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Handbook on Limestone and Dolomite for Illinois Quarry Operators

J. E. Lamar

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Handbook on Limestone and Dolomite for Illinois Quarry Operators

J. E. Lamar

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Topographic mapping in cooperation with the United States Geological Survey.

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Handbook on Limestone and Dolomite for Illinois Quarry Operators

J. E. Lamar

Abstract

Many geological and technical questions about Illinois limestones and dolomites have been asked from time to time by members of the Illinois quarrying industry and those associated with or interested in it.

This report attempts to answer many of these questions. It includes data on resources and on means of studying and testing the composition, texture, and other properties of limestone and dolomite.

Introduction

For many years and on numerous occasions, members of the Industrial Minerals Section of the Illinois State Geological Survey have discussed a wide variety of geological and technical aspects of the limestones and dolomites of Illinois with members of the quarrying industry, ranging from executives of established firms to those entering, or considering entering, the stone business for the first time. Almost invariably, questions of a geological or technical nature arose that could not be answered adequately because of lack of time or other limitations. This publication attempts to answer many of those questions. It presents a simple discussion of the geology of Illinois limestones and dolomites and related matters and also gives a brief account of the various means of studying and testing the composition, texture, and other properties of these rocks in the laboratory. Its aim is to provide for quarry operators of Illinois and those concerned with the technical aspects of stone production and utilization a basis for a better understanding of the stone resources of the state, of the properties of limestone and dolomite that affect their development and use, and of the various tests and procedures

used in studying these properties. It also provides background information that will assist them in the use of geological and technical reports about limestone and dolomite.

Definitions

The term limestone probably was originally applied to any stone from which lime could be made. It is now used as a general term to describe consolidated rocks that are composed chiefly of the chemical compound calcium carbonate, which occurs as the mineral calcite, or of calcium and magnesium carbonate, which occurs as the mineral dolomite. Rocks having such chemical compositions are also known as calcareous rocks.

The terminology applied technically to the calcareous rocks by the limestone processing and consuming industries is not always entirely consistent with that used by geologists and mineral technologists. However, in this publication the consolidated calcareous rocks of Illinois are considered to be of two major kinds—limestone and dolomite. The term "limestone" is applied to those rocks consisting principally of the mineral calcite, and the term "dolomite" is used to identify rocks consisting principally of the mineral dolomite. Some Illinois limestones contain various amounts of the mineral dolomite and are herein referred to as dolomitic limestones. Pure limestone would be 100 percent calcium carbonate, and pure dolomite 100 percent calcium magnesium carbonate.

Two frequently used industrial terms, high-calcium limestone and high-magnesium dolomite, are employed here in a common usage to indicate limestones containing more than 95 percent calcium carbonate and dolomites containing more than 20 percent magnesium oxide, which is equivalent to 42 percent magnesium carbonate.

Many new technical terms, designed to make the description of limestones more exact and definitive, have been introduced into the geologic literature in recent years. Publications by Ham (1962) and Friedman (1965) afford information and bibliographies regarding these terms.

Chemical Terms Relating to Composition

Because the chemical composition of limestones and dolomites will be referred to frequently in the subsequent discussions, a brief explanation of the chemical terminology is given here.

Chemical formulas are actually a rather simple type of shorthand, although they may seem confusing at first inspection. An example of why such shorthand is used and the sort of abbreviations involved follow. Suppose a concrete mixture consists of: Cement—1 part, Sand—2 parts, Stone—3 parts. If it were necessary to write out this composition many times, it would be convenient to abbreviate it. The 1 part of cement could be represented by

C, the 2 parts of sand by S_2, and the 3 parts of stone by St_3. By putting these together, a formula for the mixture could then be written C, S_2, St_3, or, omitting the commas, CS_2St_3. If the mixture consisted of 2 parts of cement, 3 parts of sand, and 4 parts of stone, its formula would be $C_2S_3St_4$.

As another example, pure calcite, the principal mineral in limestone, consists of 1 unit of calcium, 1 unit of carbon, and 3 units of oxygen. Ca is the chemical symbol for calcium, C the symbol for carbon, and O for oxygen. If these are combined, the chemical formula for pure calcite is $CaCO_3$.

Below are listed the chemical formulas and the names of the compounds most commonly reported in the chemical analyses of limestones and dolomites. Some analytical terms also are defined.

CaO	calcium oxide (lime)
$CaCO_3$	calcium carbonate
MgO	magnesium oxide (magnesia)
$MgCO_3$	magnesium carbonate
$CaMg(CO_3)_2$ (or $CaCO_3 \cdot MgCO_3$)	calcium magnesium carbonate
SiO_2	silicon dioxide (silica)
Fe_2O_3	ferric oxide (iron oxide)
FeO	ferrous oxide (iron oxide)
Al_2O_3	aluminum oxide (alumina)
R_2O_3	usually chiefly Fe_2O_3 and Al_2O_3 together but may also include lesser amounts of other oxides
Na_2O	sodium oxide } Sometimes referred to together as "alkalis"
K_2O	potassium oxide }
P	phosphorous
P_2O_5	phosphorous pentoxide
MnO	manganese oxide
S	sulfur
SO_3	sulfur trioxide
H_2O	water
CO_2	carbon dioxide
Loss on ignition	the weight lost by a sample of rock when it is heated at 1000°C for 1 hour or until its weight does not change. Limestones and dolomites lose CO_2, H_2O, S, SO_3, organic matter, and possibly other substances.

Materials in Limestones and Dolomites

Carbonate Components

The mineral calcite (fig. 1), which is the principal component of limestone, generally is white or gray but impurities either within or between the calcite particles may make a limestone brown, yellow, bluish gray, pink, red, green, gray, or even black. Calcite has a specific gravity of 2.710, which is equivalent to about 169 pounds per cubic foot, and hardness of 3 on the Mohs scale (see p. 89). It breaks readily into small blocks.

FIG. 1—Three specimens of calcite showing two of the many forms in which the mineral crystallizes. These specimens are parts of linings of cave-like openings in limestone. Calcite cleaves or breaks readily into rhomb-shaped blocks, some of which also are shown. The central cluster of crystals is 2¼ inches high.

The mineral dolomite, the major constituent of the rock dolomite, also occurs mainly as white or gray crystalline particles, but impurities may impart other colors. Most of the crystalline dolomite particles composing Illinois dolomites contain a small amount of iron in the ferrous state that is colorless. As long as the dolomite is protected from the weather, the ferrous iron remains unchanged and has little or no effect on the color of the stone. However, when the stone is exposed to the weather, as it is in the wall of a building, the ferrous iron oxidizes or "rusts" and is changed to another compound, a hydrated iron oxide that turns the rock yellow or brown. Some comparatively thin but extensive limestones in Illinois contain ferroan dolomite (Graf, 1960, p. 40), so called because of its relatively high iron content. They, too, commonly weather yellow or brown.

The mineral dolomite has a hardness on the Mohs scale of 3.5 to 4 and a specific gravity of 2.8 to 2.9, which is the equivalent of about 176 to 181 pounds per cubic foot.

Coarsely crystalline calcite occurs in some limestone deposits as veins (fig. 2), chiefly vertical or nearly so, that occur along joints or at random in

a stone deposit, as crystalline linings or fillings of small cavities, or as irregular masses scattered throughout the stone. Veins and cavity fillings are found in dolomite but usually more rarely than in limestone. Most calcite veins and cavity fillings are white or transparent and glassy looking. The irregular masses also usually look glassy. Very often occurrences of calcite in limestones or dolomites, especially cavity fillings, are mistaken for the mineral quartz. If they are quartz they cannot be scratched with a knife, but if they are calcite, a knife will scratch them easily.

The mineral aragonite is another calcium carbonate mineral that has been found in a few caves and cavities in Illinois limestones. It is similar in composition to calcite, but its crystals have a different form. In time it may change to calcite.

Noncarbonate Components

Chert

One of the most abundant, if not the most abundant, noncarbonate component in some Illinois limestones and dolomites is chert, sometimes called flint (fig. 3). It occurs as rounded or disc-shaped balls or nodules, from less than an inch to a foot or more in diameter, or as layers generally less than a foot thick. Abundant chert is characteristic of some limestone and dolomite formations.

FIG. 2—Calcite veins in fine-grained limestone. The specimen is 6 inches across from left to right.

Chert is composed principally of numerous very minute crystalline particles of silica (SiO_2) occurring as the mineral quartz. It has a Mohs hardness (see p. 89) of 7 and is more or less abrasive to crushing equipment. The specific gravity of 11 samples of Illinois chert (Woolf, 1953, p. 3; Lamar, 1953, p. 16) ranged from 2.05 to 2.50 and averaged 2.31. The weight per cubic foot varied from 128 to 156 pounds and averaged 144 pounds. Some chert is dense and porcelain-like, but some is porous. Some of it contains holes that are molds of fossils; other holes are lined with distinct crystals of quartz. Chert varies in color, but white or near-white, gray, and yellow are common. Some chert is unsound in concrete and a maximum allowable percentage is commonly specified for concrete aggregate and some other uses.

It is possible that some of the chert in Illinois limestones and dolomites, particularly that occurring in extensive beds or layers, was formed as a result of the consolidation of silica gel deposited on the sea floor at the time the rocks were being formed. However, Biggs (1957) suggested that the

FIG. 3—Chert nodules from western Illinois limestone beds. Nodules may have many other shapes. The large "cannonball" chert specimen is 8 inches in diameter.

chert nodules in Illinois limestones and dolomites are the result of the concentration, around a nucleus, of silica that was originally distributed throughout the immediately adjacent rock. The presence of moisture in the stone facilitated rearrangement of the silica. To what extent the beds of chert may have had a similar origin has not been investigated.

Clay and Shale

The clay in limestones and dolomites occurs as very thin partings between beds, as layers separating strata of limestone or dolomite, and as small particles or masses scattered throughout the rocks themselves. The clays consist of minerals, known as clay minerals, of which there are four major kinds in Illinois limestones and dolomites—illite, chlorite, kaolinite, and mixed-layer assemblages (Ostrom, 1959, p. 118). The mixed-layer materials, particularly, swell when wet.

The clay in calcareous rocks obviously reduces their purity. It also may interrupt the interlock between the crystalline particles composing the rocks and thus reduce their strength and resistance to weathering. If the clay occurs as bands or partings, it constitutes planes of weakness in the stone. The bands and partings may absorb moisture which, if it freezes, can cause the stone to break. Clays that swell when wet also may set up disruptive stresses in the stone, especially if the clays occur in bands or sizable masses.

In many limestones and dolomites the clay mineral material occurs as layers of shale, a rock that is a hardened clay. It may produce the same phenomena ascribed above to clay.

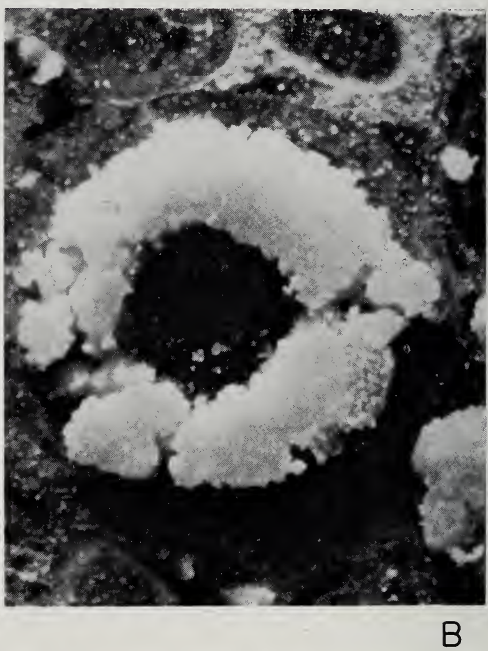
The clays and shales occurring in limestone and dolomite and as layers in deposits of these rocks vary in color, ranging from white to black. Some calcareous rocks, especially limestones, also contain red or green clays that owe their color to iron compounds. To a considerable degree the color of many limestones and dolomites is related to the color and amount of clay they contain.

Most clays and shales in Illinois limestone and dolomite deposits probably were deposited at the same time the rocks themselves were being formed. This excludes clays that have been introduced by water as fillings in underground channels, cavities, and surficial openings.

Sand, Silt, and Secondary Silica

Some Illinois limestones and dolomites contain grains of sand composed of the mineral quartz (SiO_2) or, rarely, beds of sandstone consisting of quartz grains cemented by calcite or dolomite. Most of the silt found in the limestones and dolomites consists of smaller particles of quartz. The sand and silt generally were deposited at the time the rocks were being formed, although there are many silt-sized particles of secondary silica (described subsequently) that had a different origin.

FIG. 4—Specimens of oolitic limestone that have been etched with acid which has dissolved the calcite of the rock but left untouched deposits of secondary silica. In A, several clusters of this material are visible, and in the lower third of the picture is a lacy network of the same material. A quartz sand grain in the upper right of the picture is identified by an X.



In B, a fossil, a segment of a crinoid stem, has been largely replaced by secondary silica and appears as a doughnut-shaped ring. Salem Limestone. Magnified 30 times.

Some limestones and dolomites contain irregular clusters or veinlets of small crystalline particles of quartz, roughly silt size (fig. 4A). In certain rocks this type of quartz more or less completely replaces fossils or fossil fragments (fig. 4B). Another variety of quartz, known as chalcedony, is composed of exceedingly fine crystalline particles. It may entirely or partly

FIG. 5—A mass of brassy yellow pyrite crystals. The mineral crystallizes in several different forms, of which the cubic form shown is a common one. Enlarged about 2½ times.

replace fossils in some limestones or dolomites. More rarely, Illinois calcareous rocks may contain sand-sized crystals of quartz. All these forms of quartz may be roughly grouped as secondary silica or secondary quartz because they were deposited in their present state after the limestones or dolomites were formed. Water in the rocks is believed to have played a major part in the formation of the secondary quartz.

Quartz sand, quartz crystals of sand size, and the masses of chalcedony in limestones or dolomites may be significantly abrasive to crushing equipment if they occur in sufficient quantity. It is not known to what extent silt and finely crystalline secondary silica, other than chalcedony, are abrasive because they occur in small particles, but, presumably, if enough of these materials is present they might exert an abrasive action.

The quartz and chert in limestones and dolomites are sometimes referred to as "free silica." In explorations for new limestone or dolomite deposits, an allowable maximum of 5 percent free silica is sometimes specified.

Pyrite and Marcasite

Pyrite and marcasite are similar minerals, both consisting of iron sulfide (FeS_2) and being brassy yellow, but they crystallize in different forms (fig. 5). They occur mostly as scattered crystals or clusters of crystals, often along joint faces, in Illinois limestone and dolomite. Some rocks contain small irregular veinlets of pyrite or marcasite, some of them so minute that

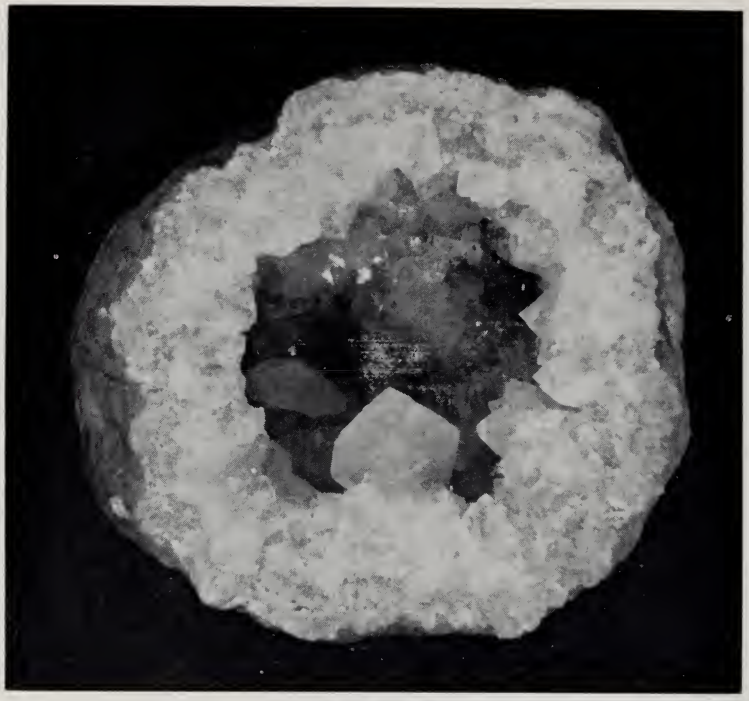


FIG. 6—A geode from a western Illinois limestone formation. It consists entirely of crystalline quartz and is lined with quartz crystals, except for the prominent "square" calcite crystal in the foreground and another behind and to the left of it. The geode is 2½ inches wide.

they appear only as black streaks. The occurrence of the two minerals is believed to be generally more common in dark gray to nearly black limestones than in lighter colored rocks. Both minerals when exposed to the weather often change to limonite or another hydrated iron oxide. Such oxides are kinds of iron rust and are usually yellow, brown, or red and may discolor the rocks in which they occur. The compounds formed as a result of the change have a greater volume than the original pyrite or marcasite and under certain conditions may cause disruptive stresses in the rock.

Geodes

Rounded nodules called geodes (fig. 6) that consist principally of quartz occur in some Illinois limestones, especially in western Illinois. Some of the geodes are almost solid; others are hollow and are lined with quartz crystals, but other minerals also may be present in the interior cavity, including calcite, dolomite, galena, pyrite, sphalerite, and kaolinite (Lamb and Lamb, 1961; Fleener, 1961). Some geodes contain petroleum. The geodes vary in size but generally are smaller than a man's head; however, some as much as 28 inches in diameter have been reported (Lamb and Lamb, 1961).

The mode of origin of geodes is not well understood, although various theories have been suggested (Fleener, 1961). They probably were formed after the limestones in which they are found. Because many of the geodes are hard to break and the quartz composing them can be abrasive to crushing equipment, they are usually regarded as undesirable materials in limestone deposits that are to be worked commercially.

Glauconite

Glauconite is a green to dark green mineral of varied composition that is a hydrous silicate of iron and potassium. It occurs as small pellets or grains in some limestones and dolomites or as finer particles dispersed throughout the rock. If present in sufficient amounts it makes stone slightly green. Not all green Illinois calcareous rocks owe their color to glauconite, however; some are colored by green clay.

Barite

Scattered crystals or crystalline aggregates of the mineral barite ($BaSO_4$) occur in some Illinois limestones but are not common. Small pinkish masses of barite have been observed locally in the LaSalle Limestone near LaSalle (Shrode, 1951, p. 126), and white barite occurs in association with fluorspar deposits in some limestones of Hardin and Pope Counties in extreme southern Illinois (Bradbury, 1959).

Organic Matter

Many Illinois limestones and dolomites contain various amounts of organic matter. The material is commonly black or brown and imparts a light gray to almost black color to the rocks in which it occurs. The darker the color the more organic matter is probably present. In parts of the Chicago area, a porous dolomite contains bitumen thought to be a residue from petroleum that once filled the pores. In Calhoun County, the Decorah limestone is brown because it contains a wax or resin. Oil can be distilled from this limestone.

If the calcite or dolomite is dissolved from limestone or dolomite by acid, the insoluble materials remaining include most of the organic matter that was in the rock. Dyni (1954) prepared and heated such residues from a variety of Illinois limestones. Some gave off an odor similar to that of burning soft coal, including those from limestones of Pennsylvanian age and from the Menard and Kinkaid Limestones; other residues had a petroleum-like odor, including those from the Decorah and Kimmswick Limestones. Some samples from the Salem and Ste. Genevieve Limestones smelled like coal and others like petroleum. The organic matter in some limestones is evidently akin to finely divided coal and in others is of a type related to petroleum.

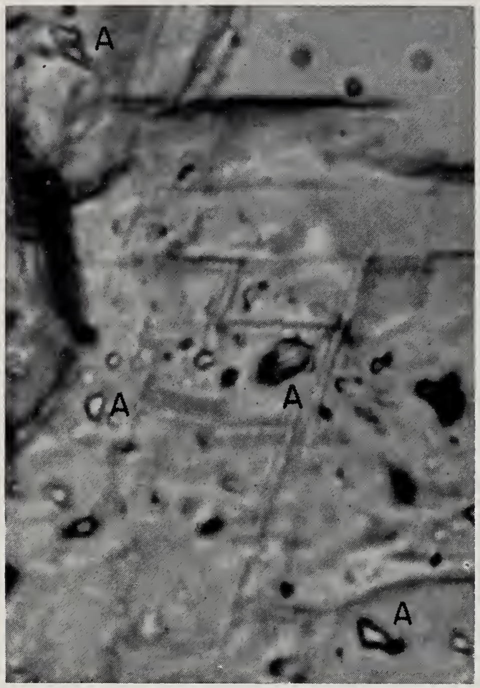


FIG. 7—Burlington Limestone containing inclusions believed to be water. Some of the larger inclusions are marked "A." Enlarged about 1300 times.

The coal-like organic matter probably was deposited at the same time as the rocks that contain it, although it may not have been in its present form. It may have been fragments of plants or trees. The bitumen and other organic matter related to petroleum found in Illinois limestones and dolomites may have been deposited with the rocks, or, if the material was petroleum at one time, may have migrated into the rocks from adjacent strata.

Fluid Inclusions

Many, if not most, Illinois limestones and dolomites contain minute inclusions believed to be water with various salts dissolved in it (fig. 7). In a study of a number of Illinois samples (Lamar and Shrode, 1953), dolomites were found to contain, on the average, a greater amount of salts than did limestones. The salts probably occurred in fluid inclusions. Among the major components present in both rocks were calcium, magnesium, potassium, sodium, bicarbonate, chloride, and sulfate. The total quantities of these substances present are small, less than about 0.3 percent. The fluid inclusions in some limestones, especially the darker colored ones, contain hydrogen sulfide gas, probably in solution in the fluid. When such rocks are crushed or pulverized, many of the fluid inclusions are broken open, releasing the hydrogen sulfide, which has a noticeably bad odor that is sometimes described as resembling crude petroleum.

Efflorescence

Some Illinois limestones and possibly some dolomites develop a white, powdery substance on surfaces exposed to the weather. This is called efflorescence, and in the case of a small number of samples examined was principally calcium sulfate. Some evidence (Lamar and Shrode, 1953) suggests the calcium sulfate originally occurred in the pores of the rocks or between the crystalline particles of the stone instead of being derived from fluid inclusions during exposure to the weather.

Other Impurities

In the lead and zinc producing area in Jo Daviess County in northwestern Illinois and in the fluorspar, lead, and zinc producing area of Hardin and Pope Counties in extreme southern Illinois, small occurrences of the minerals galena (lead sulfide, PbS) and sphalerite (zinc sulfide, ZnS) are found in limestones or dolomites and are not related to ore deposits. Fluorspar (fluorite, CaF_2) occurs similarly in southern Illinois. Outside these areas, crystals of galena and sphalerite and, more rarely, crystals of fluorite, are found occasionally. Their occurrence is so infrequent, however, that they generally cannot be regarded as important impurities in Illinois calcareous rocks.

Some limestones and probably some dolomites contain small amounts of sand-sized particles of a variety of mineral grains other than those already mentioned. They are likely to be most common in sandy limestones and dolomites. Geologists refer to them as "heavy minerals" because they are heavier than quartz.

An examination (Lamar, c. 1925) of the insoluble material left after acid treatment of a large number of limestone samples from the Chesterian Series of rocks of extreme southern Illinois, revealed in many a few grains of one or more of the minerals zircon, tourmaline, rutile, ilmenite, garnet, white mica, and other not certainly identified mineral grains. None of the minerals is present in amounts sufficient to affect the common uses of limestones and dolomites. This is probably true for other Illinois limestones and dolomites.

At a very few places, scattered, black phosphatic nodules are known to occur in Pennsylvanian limestones. However, as the limestones are less than 6 feet thick and occur under heavy overburden, it appears unlikely that the value of the phosphate present would offset the high quarrying costs resulting from the thinness of the limestones and the thick overburden.

Trace Elements

Trace elements in limestones and dolomites are elements that occur in very small amounts. A maximum of 0.1 percent has been suggested (Keller, 1950, p. 122). Many trace elements are important for the growth of animals and plants. Agricultural limestone has been proposed as a source of certain

TABLE 1—TRACE ELEMENTS IN 90 ILLINOIS LIMESTONE SAMPLES

Trace element	Amount (% by wt)	Trace element	Amount (% by wt)
Barium	0.0260	Nickel	0.0015
Boron	0.0018	Potassium	0.16
Chromium	0.0011	Sodium	0.07
Copper	0.0018	Strontium	0.049
Iron	1.13	Titanium	0.04
Lead	0.0026	Vanadium	*
Manganese	0.14	Zinc	0.004
Molybdenum	0.0001		

* Present as trace in only three samples.

amounts of these elements for plants. The trace elements in 90 samples of Illinois limestones of Pennsylvanian age were studied by Ostrom (1957, p. 29). The average amounts for the 15 trace elements for which tests were made are shown in table 1. The quantities varied greatly in different samples. Other data on minor compounds in limestone and dolomite are given in table 7.

Textural Characteristics

Definition and Character

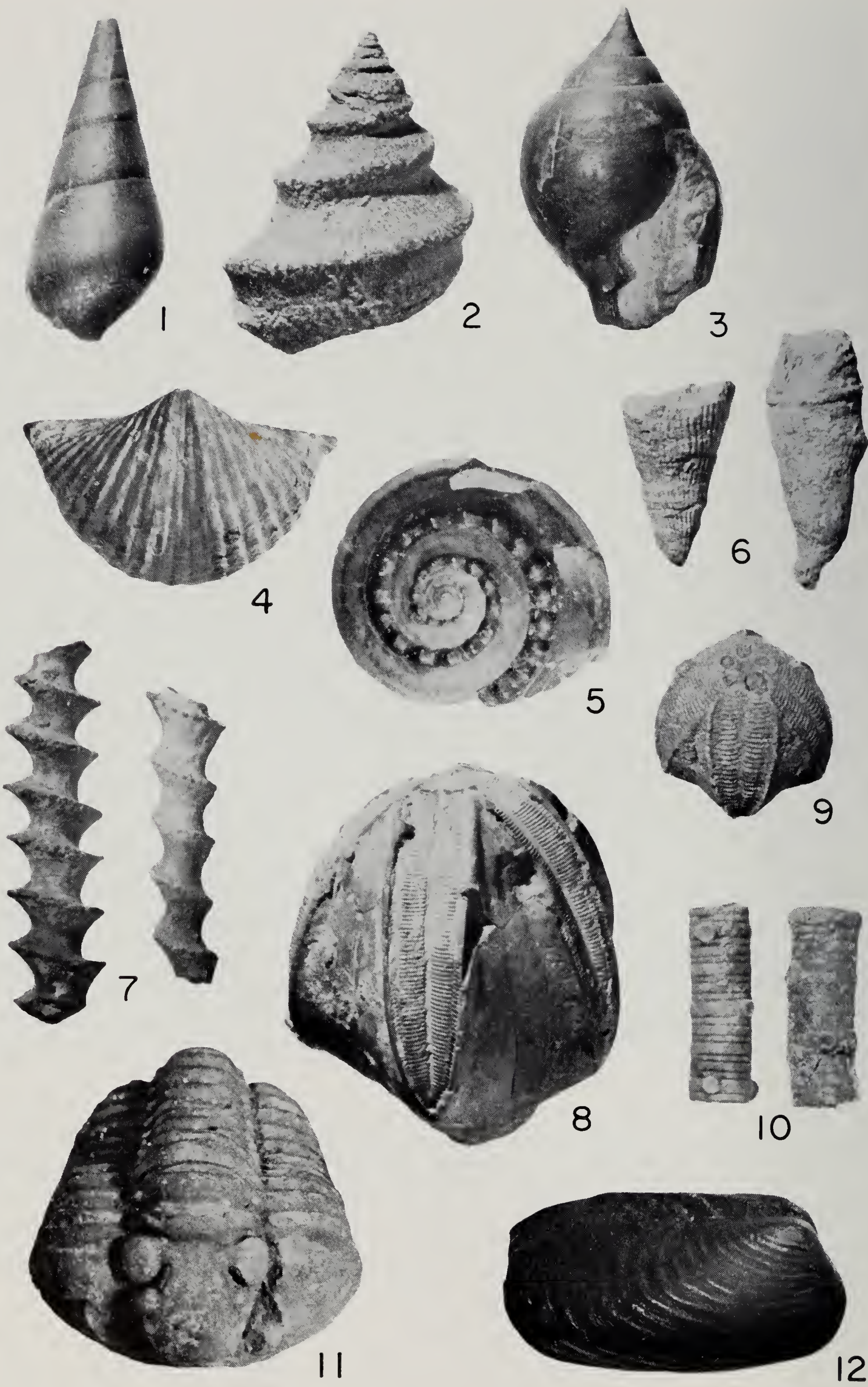
The term "texture" as applied to limestones and dolomites generally relates to the kind, arrangement, size, and manner of aggregation of the particles composing the rocks. Many classifications of texture have been proposed, among them those of Hirschwald (1912, p. 508-522), Shvetsov (1958, p. 292), Teodorovich (1958), Folk (1959), Wolf (1960), and Ham (1962).

The use of most of these classifications commonly involves the preparation of thin sections or the examination of specimens under the microscope. They are, therefore, not widely used by the quarryman who usually deals with the rocks as viewed by the naked eye. On this last basis, the principal kinds of calcitic material composing Illinois limestones are fossils and pieces of fossils, oolite grains, and crystalline calcite. The fossil material may range from clearly visible fossils or pieces thereof to small barely recognizable fragments (fig. 8). Figure 9 shows several kinds of fossils that occur in Illinois limestones. Limestones that contain an abundance of fossils or fossil fragments are described as being fossiliferous, that is, fossil bearing.

Fossils

Limestones or dolomites that contain an abundance of a single fossil are in some cases called by the name of the fossil, crinoidal limestone, for instance, for one containing abundant crinoid remains (fig. 8), coralline dolomite or limestone for those made up largely of coral material (fig. 10), and algal limestone for those with plentiful remains of algae (fig. 11).

FIG. 8—Fossiliferous limestone that has been naturally weathered so that the fossil material composing it is readily visible. The round disks are fragments of crinoid stems. The barrel-shaped or rod-like pieces are parts of the stems that have remained intact. See, for instance, the piece just above the center of the left-hand edge of the picture and another somewhat above the center of the right-hand half of the photograph. (Other crinoid stems are shown in figure 9.) Limestone such as this, composed of crinoid material, is sometimes called crinoidal limestone. The sample pictured comes from the Burlington Limestone and was taken from an outcrop near Quincy, Illinois. Enlarged 2.8 times.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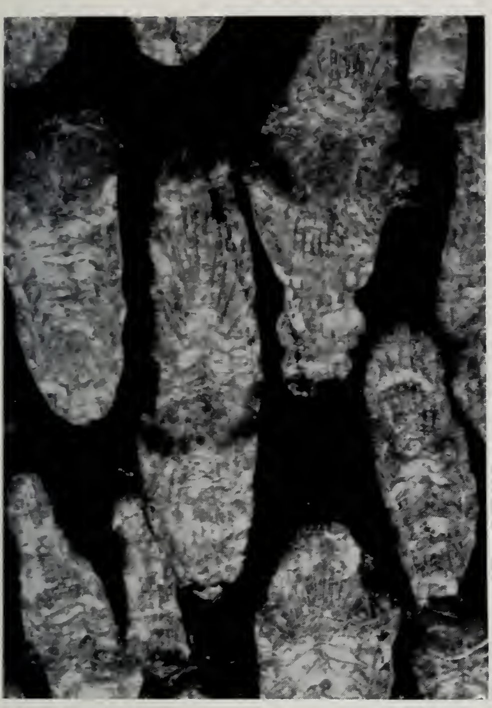

FIG. 10—St. Louis Limestone containing corals. The corals are cut parallel to or at an angle to their longest dimension. Polished surface. Enlarged 1 1/5 times.

Oolites

Oolite grains are small rounded pellets, usually consisting of a center around which are one or more layered deposits (figs. 12, 13, 14). The centers are commonly pieces of fossils (more rarely complete fossils), pieces of limestone, or sand grains. A limestone that consists entirely or largely of oolite grains in a calcite matrix is in some cases called an oolite, such as the Noix Oolite. A limestone that contains oolite grains along with fossils and/or fossil fragments in a calcite matrix may be called an oolitic limestone. In Illinois the Ste. Genevieve Limestone is generally an oolite, as are some parts of the Salem Limestone and some limestones occurring in the Chesterian Series. Other parts of the Salem Limestone and other limestones are oolitic.

Some producers or users of limestone, particularly in the building stone field, consider limestone to be of three textural sorts, oolitic, dolomitic, and

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FIG. 9—Several kinds of fossils found in Illinois limestones and dolomites. All are the petrified remains of marine animals or parts thereof. Their scientific names and the amount of magnification are given.

1. Gastropod. × 3.5.
2. Gastropod. × 1.3.
3. Gastropod. × 2.8.
4. Brachiopod. × 1.4.
5. Gastropod. × 2.5.
6. Corals. × 2.0.
7. Bryozoa (Archimedes screw). × 2.8.
8. Pentremite. × 1.4.
9. Pentremite. × 2.3.
10. Crinoid stems. × 1.4.
11. Trilobite. × 2.8.
12. Pelecypod. × 1.3.

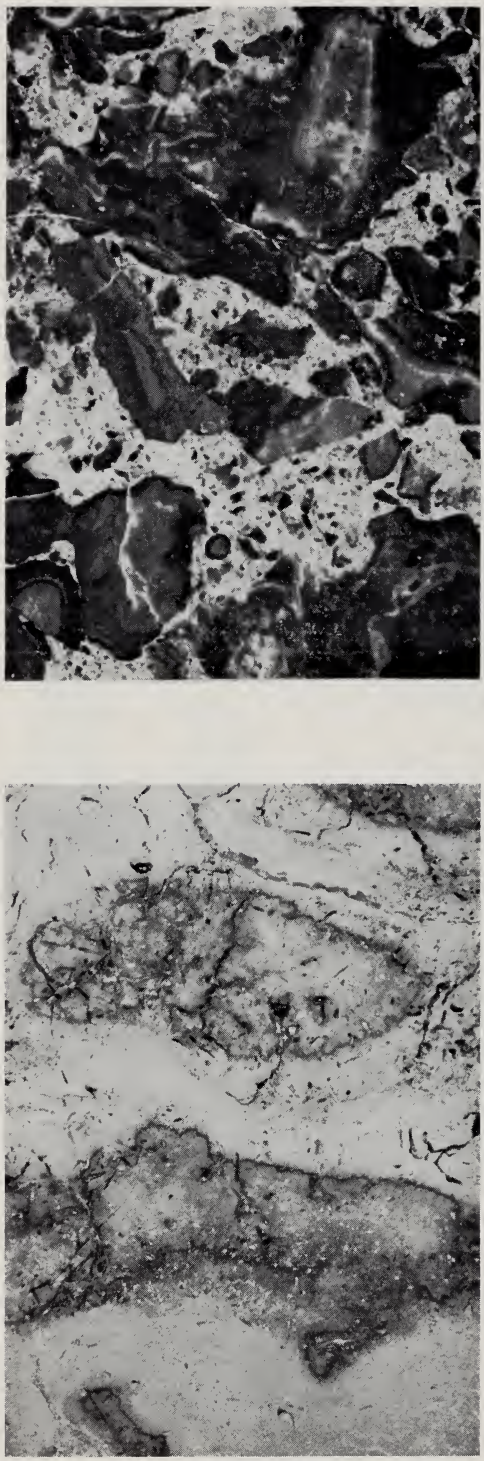

FIG. 11—Algal limestone. Top specimen was obtained from the St. Louis Limestone near Alton. The concentric structure of the algal growths is shown in the upper right corner. Polished surface. Enlarged 3 times. Bottom specimen came from the Millersville Limestone near Casey. Polished surface. Enlarged 1 1/5 times.

FIG. 12—Broken surface of a piece of oolite from the Ste. Genevieve Limestone near Anna. Some oolite grains are whole, some have lost a part of an outer concentric layer. A few grains have been broken in half and show dark cores surrounded by a white concentric deposit. The shell-like depressions are the outer layers of oolite grains that have broken away. Enlarged 10 times.

FIG. 13—Oolite grains that have broken free from an oolitic limestone, showing the elongate and often lumpy nature of such grains. Magnified 11 times. (Photograph by R. S. Shrode.)

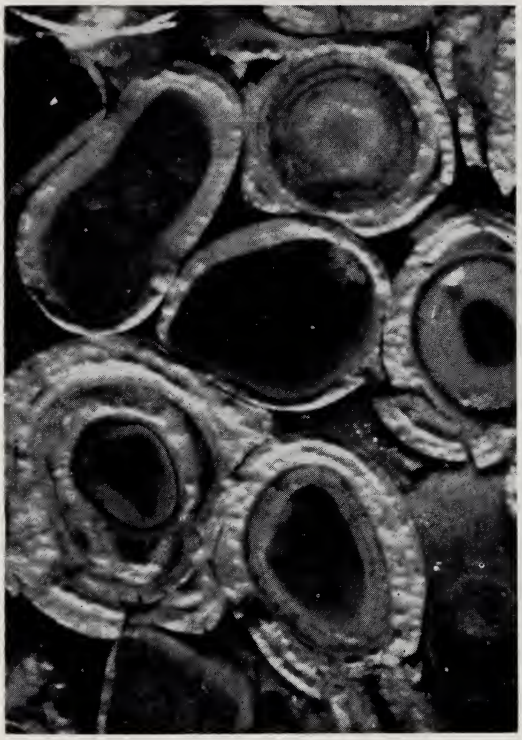

FIG. 14—Oolite from the Ste. Genevieve Limestone at Anna. Some of the grains have centers of clear calcite, which appears black. The number of rings around the grain centers varies from 1 to 6 or even more. The dark areas between the grains are filled with clear calcite. The specimen was slightly etched to bring out its texture. Magnified 22 times.

crystalline. Another usage recognizes the varieties of limestone as oolitic, crystalline, semicrystalline, dolomite, and coquina (U. S. Gen. Serv. Adm., 1955, p. 1).

Crystallinity

Basically, all limestones and dolomites, including the fossiliferous materials and the oolites, are crystalline in the sense that they are made up of crystalline particles (figs. 15 and 16). However, in the quarrying industry the term crystalline is often used to describe rocks that seem to be made up primarily of crystals rather than of pieces of fossils or oolites when viewed by the naked eye.

No generally employed limits or terms relating to the size of the crystals composing a crystalline limestone or dolomite or of the size particles making up an oolite or a fossiliferous limestone are known to be in common use among quarrymen. Nor do all geologists describe crystal or grain size in the same way (Ham, 1962, p. 52 and 74). However, much of the Burlington Limestone of western Illinois and of the Kimmswick Limestone in southwestern Illinois would probably be considered by Illinois quarrymen to be coarsely crystalline. At the other extreme, the St. Louis Limestone in southwestern Illinois and the Kinkaid Limestone in extreme southern Illinois

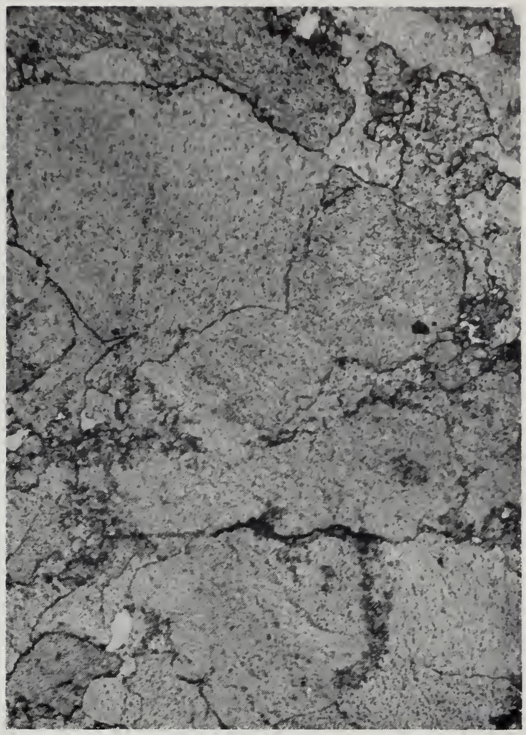

FIG. 15—A thin section of Burlington Limestone from western Illinois. The coarse nature of most of the crystalline particles of calcite composing the specimen is evident. A number of smaller crystalline particles fill the spaces between the larger ones. This type of limestone generally would be called crystalline by quarrymen. Magnified about 20 times.

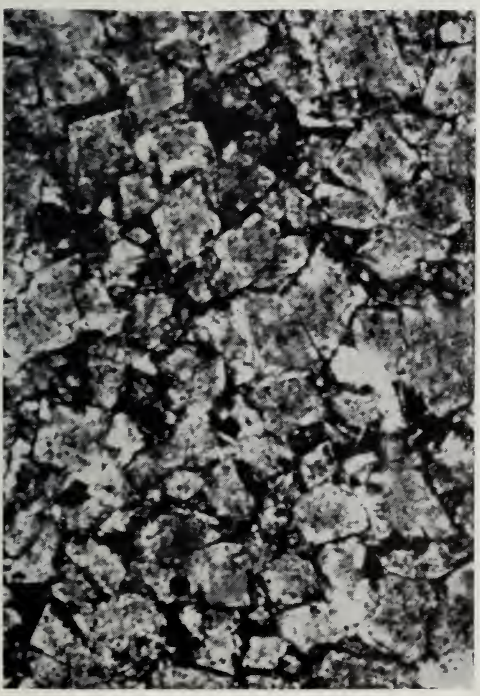

FIG. 16—Photomicrograph of a thin section of dolomite showing numerous individual rhomb-shaped grains. Magnified 50 times. Galena Dolomite near Elizabeth.

contain numerous strata likely to be called very finely crystalline limestone. The term "lithographic limestone" is sometimes applied to extremely fine crystalline limestone that has a very uniform character and is free of coarse particles. Its crystalline particles are too small to see with the naked eye. Such "stones" at one time were extensively used by lithographers in making illustrations for books and other publications. Very finely crystalline limestones also are sometimes called amorphous limestones.

Most of the dolomites of Illinois are likely to be considered as medium or finely crystalline, although some coarsely crystalline dolomite has been reported locally. Some dolomites are quite fossiliferous, but the fossils are usually not as well preserved as those in limestone. No outcropping dolomites containing oolites that are themselves made up of the mineral dolomite have been found in Illinois.

Grain Size

The terms fine, medium, or coarse grained are often applied to the limestones and dolomites of Illinois, but no grain-size limits are known to be in general use in the stone industry. The term "grained" is commonly used to describe the textures of limestones and dolomites regardless of whether they are primarily crystalline or fossiliferous. For example, a coarse-grained lime-

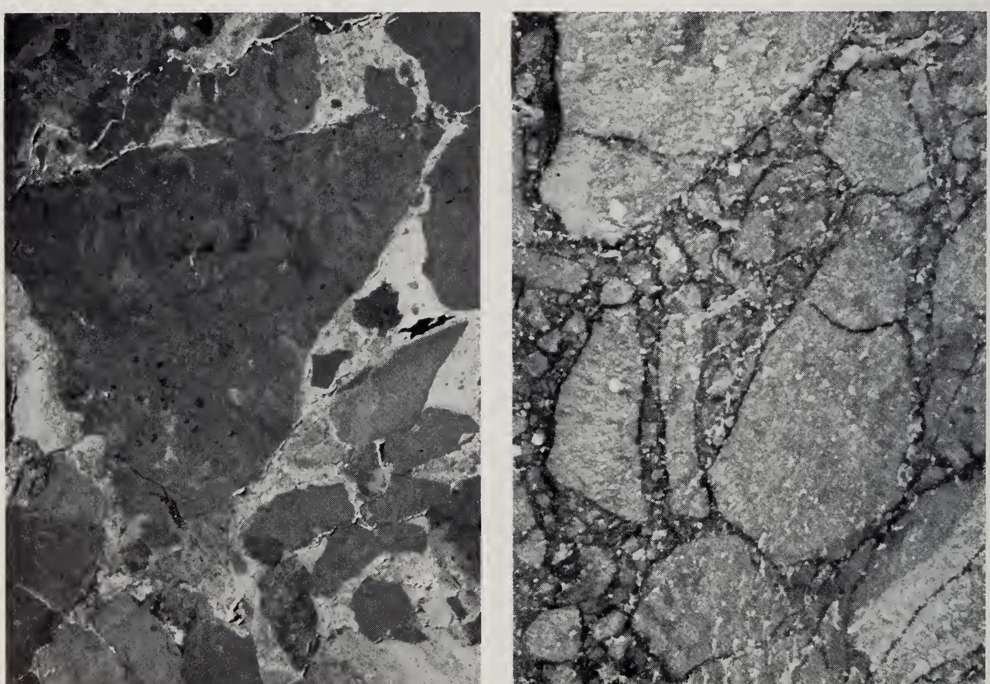

FIG. 17—Brecciated limestone. Specimen on left obtained near Alton. Polished surface. Enlarged 1.2 times. Specimen on right came from near Colchester. Broken surface. Enlarged 1.4 times. Both samples are from the St. Louis Limestone.

TABLE 2—DOMINANT GRAIN SIZE OF THE MAJOR COMMERCIAL LIMESTONES AND DOLOMITES OF ILLINOIS *

(Arranged in order of age from the youngest at the top to the oldest)

Name	Principal kind of rock	Dominant grain size
Omega	Limestone	Fine to medium
Livingston †	Limestone	Fine to medium
Millersville †	Limestone	Fine to medium
LaSalle ‡	Limestone	Fine to medium
Shoal Creek ‡	Limestone	Fine to medium
Pontiac ‡	Limestone	Fine to medium
Lonsdale	Limestone	Fine to medium
Seville	Limestone	Fine
Kinkaid	Limestone	Fine to medium
Okaw	Limestone	Fin to medium; some oolite
Ste. Genevieve	Limestone	Fine to medium; much oolite
Fredonia	Limestone	Fine to medium; much oolite
St. Louis	Limestone	Fine to medium; some very fine; some oolite
Salem	Limestone	Fine to coarse; some oolite
Ullin	Limestone	Medium to coarse
Burlington	Limestone	Fine to coarse; much coarse
Cedar Valley	Limestone	Fine to medium
Wapsipinicon	Limestone	Fine to medium
Niagaran	Dolomite	Fine to medium
Galena	Dolomite	Fine to medium
Kimmswick	Limestone	Medium to coarse
Platteville	Limestone and dolomite	Fine to medium; much fine
Plattin	Limestone and dolomite	Fine to medium
Shakopee	Dolomite	Fine
Oneota	Dolomite	Fine to medium

* Limestones and dolomites in which one or more quarries are known to have been worked recently.
† Different names for the same limestone stratum.
‡ Different names for the same limestone stratum.

stone might consist of coarsely crystalline particles of calcite, of coarse fragments of fossils, or of coarse oolite grains. Table 2 shows the dominant grain size, as it might be described by Illinois quarrymen, of the major commercial limestones and dolomites of Illinois.

Breccias, Conglomerates, and Nodular Limestones

The adjective "nodular" is employed to describe some Illinois limestones, such as parts of the LaSalle and Lonsdale Limestones, that are made up of nodules. These are rounded, though not necessarily spherical, pieces of limestone that occur in a softer, usually clayey matrix. The lumpy character of the rock is especially evident on weathered surfaces where the softer matrix has weathered away more rapidly than the nodules. Usually nodular limestones are comparatively impure.

In western and southwestern Illinois the St. Louis Limestone contains, in places, beds of breccia or conglomerate (fig. 17). Brecciated limestone

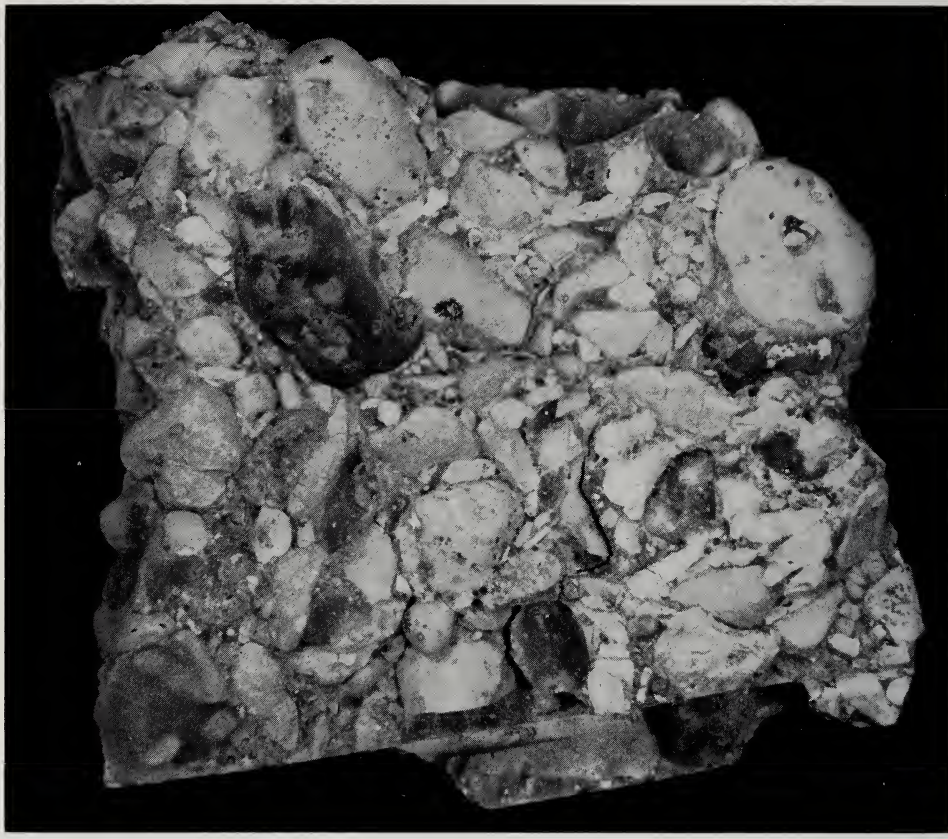

FIG. 18—Limestone conglomerate consisting of rounded limestone pebbles in a matrix of fine-grained limestone. Broken surface. "Glen Park" formation, north of Atlas. Enlarged 1.2 times.

consists of angular fragments of limestone, broken by natural forces from a once solid bed, that are now held together by a matrix. Conglomerate is a similar material but consists of rounded pieces of limestone in a matrix (fig. 18).

Laboratory Studies of Texture

A variety of procedures, described later in more detail, are used in the study of limestone and dolomite textures in the laboratory. They include direct examination of a specimen under a microscope (usually a binocular microscope), preparation and examination of thin sections (generally with a petrographic microscope), preparation of cellulose nitrate peels or other types of peels (Bissell, 1957, McCone, 1963) for examination with the microscope, microscopic examination of polished surfaces and of specimens of limestone or dolomite whose surfaces have been etched with acetic or hydrochloric acid (Lamar, 1950).

None of the foregoing requires highly complicated equipment or great skill except the making of thin sections. A diamond saw and power-driven grinding laps are desirable for preparing specimens. However, interpretation of the features revealed by the various procedures generally involves geologic knowledge, but the kinds and distribution of the impurities revealed by etching are comparatively obvious.

Color

The color of Illinois limestones and dolomites results in large measure from impurities within or between the crystalline particles the rocks are made of. Organic material, mentioned earlier in the discussion of impurities is responsible for most shades of gray and black. Yellow and brown are usually due to hydrated iron oxide, reds also are due to iron compounds, either hydrated iron oxides or hematite (iron oxide, Fe_2O_3). Greenish stone is rare in Illinois and its color generally is due to glauconite grains or to greenish clay. The reds, browns, and yellows in limestones and in some dolomites also may be caused by clays that are colored by iron compounds. Only a fraction of one percent of most of the iron compounds is needed to produce a distinct color in a limestone or dolomite.

Formation of Limestone and Dolomite

Limestone

All the limestones of present commercial importance in Illinois were formed in oceans that on numerous occasions covered all or much of the state. In many of these seas abounded shell fish of various kinds whose hard parts were composed of calcium carbonate. When they died their hard parts, whole or in pieces, accumulated in great quantities. A lime mud filled the spaces between the animal remains. As time passed and other deposits buried the animal remains and lime mud, the mass was compacted. In some instances the lime mud was recrystallized into coarser grained calcite. The animal remains became the fossils and fossil detritus now visible in all but a few Illinois limestones. Those few largely devoid of fossil material probably were deposited primarily as lime mud.

In shallow areas of the oceans, for example, in and adjacent to tidal flats, layers of calcium carbonate were deposited around fragments of shells or other animal hard parts, or even around small shells, forming small rounded pellets that are called oolite grains, ooids, or ooliths. These pellets accumulated where they were formed or were transported by waves or currents, much as sand is in present-day oceans, and built up extensive bars and beaches or deposits on the sea floor. Subsequent hardening of lime mud associated with the oolite grains produced the consolidated rock called oolite or oolitic limestone.

The history of many of the limestones from their original deposition to the present appears to have been complex. Compaction of some of the original

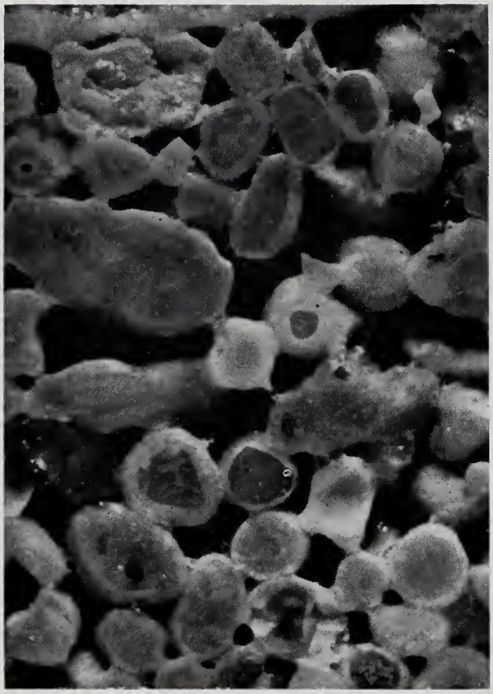

FIG. 19—A piece of porous oolite with a smoothed surface from a well in the Clay City oil field. The black areas are holes that are believed to have been filled at one time by calcite cement. Ground water has dissolved away the cement and produced the pores. Parts of some oolite grains, such as the white grain at the center of the picture, also have been partially dissolved. Magnified 26 times. Ste. Genevieve Limestone.

materials is shown by the flattening of some of the fossils. Solution has removed parts of some limestones as shown by the oolite grains in figure 19. Water moving through limestone also may remove calcite and later add coarser grained deposits of calcite at the site of the initial deposit.

The oceans in which some limestones were formed persisted for a very long time, and hundreds of feet of limestone accumulated. As little mud or sand was being brought into the parts of the ocean where the limestones were forming, they consist very largely of calcium carbonate. In other places in the same ocean, or at other times in other oceans, however, clay or sand was brought into the seas and deposited in layers with which limy material was mixed. This happened most often in parts of the oceans near shore where streams deposited their loads of sand and clay worn away from the adjacent land areas. The sand deposits are now sandstone and most of the clay deposits are compacted clay called shale; however, some original clay deposits underwent very little compaction and even today appear as clay. The beds of shale and sandstone and many of the bands of shale or clay found in Illinois limestones and dolomites have had a similar origin.

Dolomite

The formation of the dolomites of Illinois has involved an additional step beyond the formation of limestone. Probably the dolomites started out as limestones and, although it is not certain, it is thought likely that while the limestones were still beneath the sea, magnesium from the sea water reacted

with the calcium carbonate of the limestone to form a new mineral, dolomite, consisting of calcium and magnesium carbonate. Another possibility that cannot be ruled out entirely is that some time after certain limestones became part of the land when the ocean withdrew, water percolating through them introduced magnesium and converted the calcite of the limestone to the mineral dolomite.

With the change of the mineral calcite to dolomite, whether beneath the sea or by ground water, the dolomite formed had a smaller volume than the calcite it replaced. This in some cases resulted in the formation of numerous readily visible pores in the dolomite, which were the means of adjusting for the decreased volume of solid material. The development of pores was generally most pronounced in the reef type of dolomite and less well developed, or absent, in the interreef beds, subsequently described.

Like the limestones from which they were formed, the deposits of dolomite rock contain fossils, bedding planes, and clay or shale partings, but the fossils usually are not as well preserved as those in limestones.

In the ancient oceans during certain periods of the geologic history of Illinois, especially the Silurian Period (see page 39), reefs, technically called bioherms, were present that probably were similar to the reefs in the South Pacific Ocean at the present time. They were built up from the hard parts of marine animals, especially corals, and hence have sometimes been called coral reefs. Many of these reefs, particularly those of Silurian age, have been changed to dolomite that is characteristically porous (fig. 20) and is called reef rock or reef-type dolomite.

The lateral and vertical extent of the ancient reefs depended on whether ocean conditions were favorable to the growth of marine animals and to the accumulation of their hard parts after they died. Conditions were rarely constant, and, as a result, the size and rate of growth of a reef varied at different times. Some reefs were of short duration and, therefore, the deposits composing them are relatively thin, whereas long-lived reefs grew to thicknesses of more than 100 feet.

The size of the Illinois reefs varies. In northeastern Illinois some of them are more than three-fourths of a square mile in area; others extend for only a few acres. Many of the quarries in the greater Chicago region contain reef rock. In northwestern Illinois reef-type dolomite also occurs in extensive deposits.

Much of the reef-type stone is of high purity, for which reason it is or has been used for making lime and clinkered dolomite, as flux, as refractory dolomite, and for many kinds of crushed stone.

The dolomite that occurs between the reefs—technically called the interreef dolomite—is usually less pure than the reef dolomite, though the amount of impurities varies greatly. Most of the interreef rock is commercially usable for some grade of crushed stone or some other purpose. Many deposits contain chert.

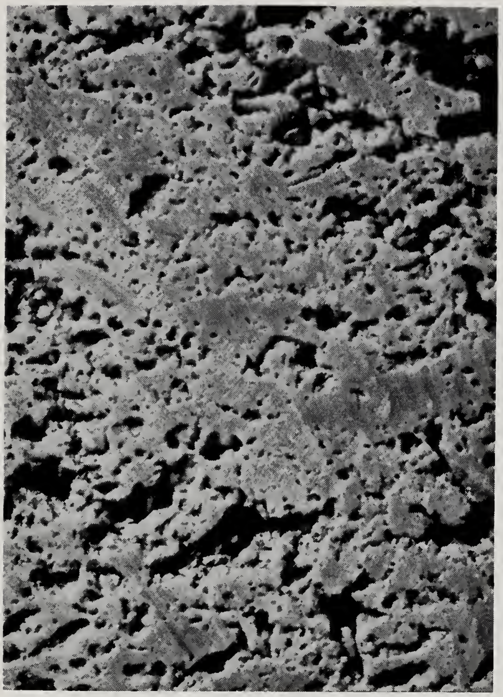

FIG. 20—Porous reef-type Silurian dolomite. Sawed surface. Enlarged 1 1/3 times.

Bedding Planes

As the limestones, both the pure varieties and those containing sandstone or shale strata, were laid down in water by a process in which settling was a very important feature, they are called sedimentary rocks. Because of their mode of formation the limestones and dolomites occur in layers called beds, or strata, that may vary from a fraction of an inch to more than 20 feet thick. A "bedding plane," sometimes referred to by quarrymen as a "break," separates the beds. The bedding planes represent a change in conditions in the ocean that resulted in a change in the kind of sediment being deposited. For example, if deposition of limestone stopped, clay was deposited briefly and then limestone deposition resumed, a bedding plane would be formed where the thin film of clay separated the two deposits of limestone. Bedding planes may originate in may other ways, for instance, with an abrupt change from the deposition of coarse fossil detritus to a lime mud, with a brief interval between the two when no sediments were being deposited. As will be discussed later, ground water moving through a limestone or dolomite deposit often follows bedding planes and makes them more prominent by dissolving some of the limestone along them. Some bedding planes are not visible in freshly quarried limestone or dolomite but become readily apparent when the stone has been exposed to the weather for a time. They frequently constitute planes of weakness along which the stone will break under the destructive effects of the weather.

TABLE 3—GEOLOGIC SYSTEMS OF ILLINOIS AND MAJOR KINDS OF ROCKS IN EACH

System	Kinds of rock	Major areas of outcrop
Quaternary	Pleistocene glacial clays, sands, silts, gravels	Surface deposits over most of Illinois
Tertiary	Clay, sand, gravel	Chiefly in extreme southern Illinois
Cretaceous	Sand, clay, silt	Chiefly in extreme southern Illinois; small area in western Illinois
Pennsylvanian	Sandstone, shale, clay, coal, limestone	Central, western, and southern Illinois
Mississippian	Limestone, sandstone, shale	Western, southwestern, and southern Illinois
Devonian	Chert, highly siliceous limestone, relatively pure limestone	Extreme southern Illinois
	Chiefly limestone, some of it pure	Northwestern Illinois
Silurian	Dolomite	Chiefly northern Illinois
	Limestone	Extreme southern Illinois
Ordovician	Dolomite, sandstone, shale	Chiefly in northern Illinois
	Limestone, shale	Western and southwestern Illinois
	Limestone, siltstone	Extreme southern Illinois
Cambrian	Dolomite	Northern Illinois

Succession, Names, Age, and Character of Rock Units

The seas in which the limestones of Illinois were formed covered the state widely, and at times sand and clay were deposited in them, which were later changed to sandstone or shale. Alternating limestone, sandstone, and/or shale beds were thus formed. The thickness of the individual deposits varied so that the deposits of some seas are made up of many relatively thin limestone, shale, and sandstone units, whereas the deposits of other seas are thick units or a combination of thick and thin units. The part of geology that deals with the various kinds of rock strata, their succession one above the other, and tracing them from one place to another is called stratigraphy.

In order to be able to discuss the different rock strata of Illinois, geologists have given them names, usually of towns or streams near which good outcrops of the rocks occur. For instance, the St. Louis Limestone is named from outcrops near St. Louis, Missouri, and the Galena Dolomite from outcrops near Galena, Illinois. As the various strata were formed at different times, it was necessary to develop a geological calendar by which to date the time of formation. This was done many years ago and the rocks of Illinois have been assigned to the systems listed in table 3.

The rocks formed during one period of time are described as composing a system. For example, the rocks deposited during the time of the Mississippian Period are called the rocks of the Mississippian System. Most systems have been divided into two or more series. Many of the names given to the systems were derived from places where the rocks are well exposed. For example, the terms Mississippian System and Pennsylvanian System come from the Mississippi Valley and from Pennsylvania, while the term Devonian System comes from Devonshire, England. The Chesterian Series of rock strata are named for Chester, Illinois. In addition, the rock sequence is subdivided into units based on their composition or character. These units are called groups, formations, and members. Groups consist of two or more formations, and members are subdivisions of formations. The units generally are named for the kind of rock they contain. St. Louis Limestone and Galena Dolomite are examples. Generally, the quarryman is concerned chiefly with formation and member names.

The amount of time that has elapsed since the earliest sedimentary rocks were deposited in Illinois is more than 500 million years. The length of the various periods and how long ago they occurred, according to recent findings, are shown in table 4.

TABLE 4—GEOLOGIC TIME SCALE*

Period	Millions of years ago	Duration, millions of years
Quaternary	1	1
Tertiary	1 – 63	62
Cretaceous	63 – 135	72
Jurassic †	135 – 181	46
Triassic †	181 – 230	49
Permian †	230 – 280	50
Pennsylvanian	280 – 310	30
Mississippian	310 – 345	35
Devonian	345 – 405	60
Silurian	405 – 425	20
Ordovician	425 – 500	75
Cambrian	500 – 600 (?)	100

* Kulp, 1961.
† No deposits made during these periods are known to occur in Illinois.

The general character and use of the limestone and dolomite of the various geologic systems in Illinois are shown in table 5. Where they are quarried and their uses are given in table 6. Production from both the Mississippian and Silurian rocks greatly exceeds in tonnage that of any of the other systems. Figure 21 shows the general distribution of the rocks of the various systems. As previously indicated, most of the systems contain rocks other than limestone and dolomite.

Distribution of Commercial Limestones and Dolomites

Figure 22 shows those areas in Illinois where limestones or dolomites crop out in places. The number of outcrops is greater in some areas than in others. The map indicates that dolomite is prevalent in northern Illinois and generally absent elsewhere, except in limited tracts in southern Jersey County and southern Pike County. Beds of dolomitic limestone are found in some other areas but generally are not common. Throughout the rest of the state, limestone is the common calcareous rock. Small amounts of limestone and dolomitic limestone occur in parts of northern Illinois.

The geologic age of the limestones and dolomites in the areas delineated in figure 22 can be ascertained from figure 21.

Distribution of Kinds of Stone and Outcrops

The bedrock of Illinois is almost everywhere covered by rock material left by one or more of the several glaciers that once extended over most of the state, or by sand, silt, or clay laid down by streams or wind and derived

TABLE 5—GENERAL CHARACTER AND USES OF LIMESTONES AND DOLOMITES ACCORDING TO GEOLOGIC AGE

System	Character	Principal commercial use
Pennsylvanian	Limestone, rarely high calcium	Agstone, road rock, some base course stone; some concrete aggregate and chips for bituminous roads; portland cement
Mississippian	Limestone, locally high calcium; some formations contain much chert, some are otherwise impure	All major uses for crushed stone, lime, flux, whiting, chemical limestone, portland cement, building stone, marble
Devonian	In western Illinois—limestone, locally high calcium; some formations impure. In extreme southern Illinois—much cherty and siliceous limestone; some comparatively pure limestone, locally high calcium	Major crushed stone uses
Silurian	Dolomite, locally high magnesium; some deposits cherty; purity variable	All major uses for crushed dolomite, including lime, refractory dolomite, flux, riprap
Ordovician	In western and southwestern Illinois—limestone locally high calcium	Various crushed stone uses; chemical limestone; pulverized limestone
	In northern Illinois—mostly dolomite, some of it high magnesium; some formations cherty; locally limestone	Various crushed stone uses; some deposits not suitable for concrete aggregate or blacktop chips; portland cement
Cambrian	Dolomite, may be high magnesium locally	Crushed stone, especially agstone and road rock

TABLE 6—LIMESTONES AND DOLOMITES QUARRIED IN ILLINOIS, AREAS WHERE WORKED, AND MAJOR USES

Name of rock unit	Kind of rock *	Areas where quarried or mined	Principal uses †
PENNSYLVANIAN SYSTEM			
Greenup	L	Cumberland County	Crushed stone
Omega	L	Effingham, Clay, Jefferson Counties	Crushed stone
Millersville ‡	L	Montgomery, Fayette, Christian Counties	Crushed stone
Livingston ‡	L	Clark, Coles, Vermilion Counties	Crushed stone
LaSalle °	L	LaSalle County	Cement making
Shoal Creek °	L	Bond, Clinton, Christian, Montgomery, Washington Counties	Crushed stone
Pontiac °	L	Livingston County	Crushed stone, mineral filler, mine dust
Lonsdale	L	Logan, Menard, Peoria Counties	Crushed stone
Seahorne	L	Greene County	Crushed stone
Seville	L	Mercer County	Crushed stone
MISSISSIPPIAN SYSTEM			
Kinkaid	L	Jackson and Johnson Counties	Crushed stone
Okaw	L	Randolph and St. Clair Counties	Crushed stone
Ste. Genevieve (including Fredonia)	L	Union, Johnson, Hardin, Massac Counties	Crushed stone, riprap, cement making, flux
St. Louis	L	Calhoun, Fulton, Madison, McDonough, St. Clair Counties	Crushed stone, whiting, riprap
Salem-St. Louis	L	Western Illinois	Crushed stone
Salem	L	Randolph and St. Clair Counties	Crushed stone, chemical stone
	L	Western Illinois	Crushed stone, riprap
Ullin	L	Union and Pulaski Counties	Crushed stone, riprap, commercial marble
Burlington-Keokuk	L	Western Illinois	Crushed stone, high-calcium lime, pulverized limestone, flux, riprap
DEVONIAN			
Wapsipinicon-Cedar Valley	L	Henry and Rock Island Counties	Crushed stone, riprap, flux
SILURIAN			
Niagaran	D	Cook, Carroll, DuPage, Jersey, Jo Daviess, Kane, Kankakee, Rock Island, Whiteside, and Will Counties	Crushed stone, riprap, refractory dolomite, flux, lime, dolomite refractories
Kankakee-Edgewood	D	Will, Kankakee, Kane, and McHenry Counties	Crushed stone

(Continued on next page)

TABLE 6—Continued

Name of rock unit	Kind of rock *	Areas where quarried or mined	Principal uses †
ORDOVICIAN			
Maquoketa	L	McHenry County	Crushed stone
Galena-Platteville	D,L	Northern and northwestern Illinois	Crushed stone, cement making
Kimmswick	L	Monroe County	Crushed stone, riprap, pulverized limestone, filler, flux
Plattin	L	Calhoun County	Crushed stone
Shakopee	D	LaSalle and Lee Counties	Crushed stone
Oneota	D	Lee County	Crushed stone
Gunter	D	Lee County	Crushed stone
CAMBRIAN			
Eminence-Potosi **	D	Lee County	Crushed stone

* L indicates limestone; D denotes dolomite.
† Agricultural limestone is included under crushed stone.
‡ These names are applied to the same limestone stratum in different parts of the state.
° These names are applied to the same limestone stratum in different parts of the state.
** Formerly Trempealeau.

originally from glacial deposits. In the main, areas of outcrop of bedrock result from the wearing away of the glacial deposits by streams. They occur commonly in the bluffs and valley walls of large and small streams, and locally in the valley flats of the streams. The kind of rock exposed depends on what kind of rock constitutes the bedrock. In the area underlain by the Pennsylvanian System, the bedrock is predominantly shale or sandstone; the areas where limestones constitute the bedrock are limited in number and size (compare the lowest map in fig. 21 with fig. 22). However, if the bedrock belongs to the Mississippian System with its many limestone units, a high percentage of the bedrock exposures are limestone (see right-hand map in fig. 21 and fig. 22).

Comparison of the maps in figure 21 shows that the rocks of the Ordovician, Silurian, Devonian, and Mississippian Systems, which include the thick limestone and dolomite formations, occur principally along the northern, western, and southern portions of the state, whereas the Pennsylvanian rocks, in which the limestones are comparatively thin, occupy the large central area.

The distribution of the various rock systems shown in figure 21 results because the rock strata, although they were flat-lying when they were formed, are now tilted in various directions and amounts. The tilting is the result of the gradual folding of the rocks by earth forces which downwarped them into a basin whose deepest part is in southeastern Illinois and whose eastern margin is in western Indiana. Thus the rocks in the rest of the state in a general way lower or dip toward southeastern Illinois. The Pennsylvanian rocks might be likened to coffee in a spoon, the older rocks to the spoon itself, and their outcrops in northern, western, and southern Illinois to the rim of the spoon.

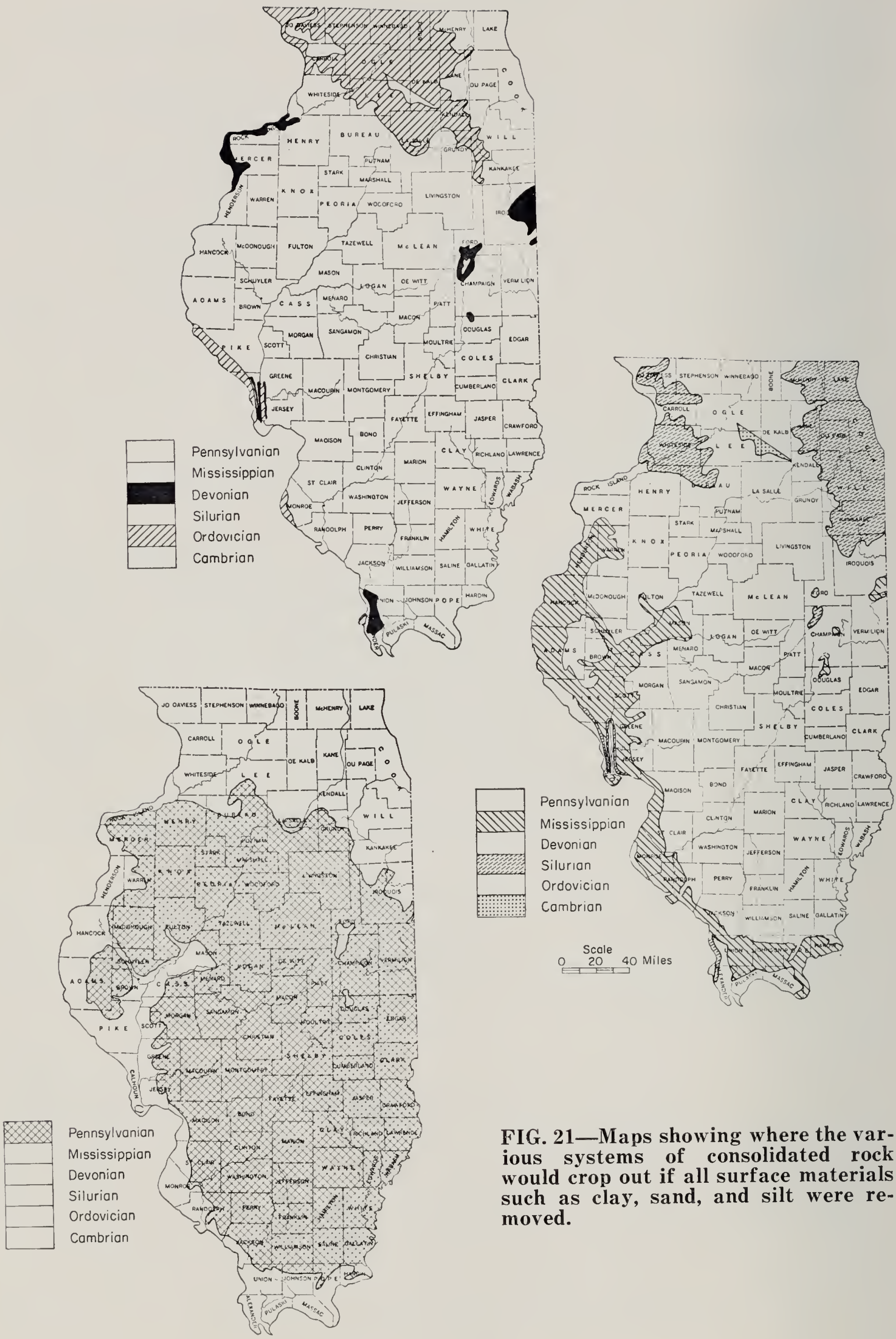

FIG. 21—Maps showing where the various systems of consolidated rock would crop out if all surface materials such as clay, sand, and silt were removed.

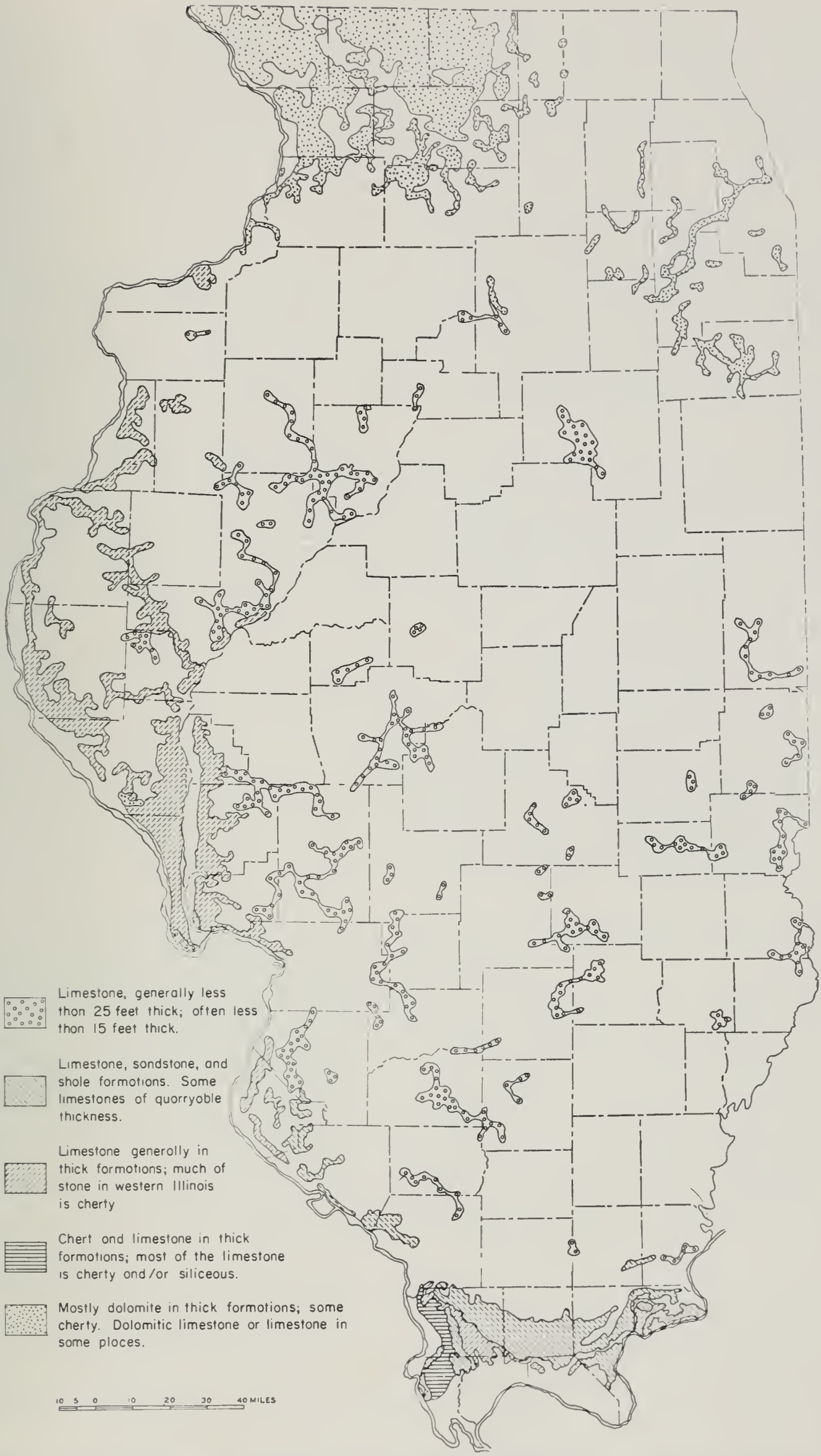

FIG. 22—Generalized map showing areas in Illinois where limestone or dolomite more than 3 feet thick crops out in places. A number of small outcrop areas not shown.

In the process of the downwarping of the Illinois Basin, a number of upfolds or wrinkles, known as anticlines, were formed (fig. 23). Some of them have considerable length and width. The largest is the LaSalle Anticlinal Belt, which extends from southeastern Illinois to beyond LaSalle in northern Illinois. Downfolds, known as synclines, were similarly formed.

Unconsolidated Overburden

The overburden on the limestone and dolomite deposits of Illinois that are now being quarried from open pits, or are likely to be so worked under present circumstances, is usually some kind of unconsolidated material, such as surface clay, silt, sand, or gravel. The most common overburden materials are loess and till. Rarely, the overburden may also include shale or sandstone bedrock.

Till is a clay containing various amounts of silt, sand, gravel, and boulders. It was deposited by glaciers. When unweathered, it is usually a medium to dark gray, but weathering changes it to yellow or brown, and the upper parts of most deposits of till are in that color range. Very gravelly or bould-

FIG. 23—Map showing the major upfolds or belts of upfolds in Illinois. Fold A is a monocline. The solid lines are upfolds (anticlines). The dashes indicate either a belt of upfolds or that the position of the crest of the upfold is not precisely known. The dotted lines indicate faults. (Modified from Bell, Oros, and Van Den Berg, 1962, p. 20.)

FIG. 24—Unglaciated areas and distribution of Cretaceous-Tertiary materials.

ery till is sometimes referred to as hardpan. The thickness of the till varies but reaches several hundred feet in some places.

Loess is a wind deposited material that in years past has been blown from the bottom lands of the major streams of Illinois and spread for many miles over adjacent upland areas. The weathered loess usually seen is brown, but loess is gray when it is unweathered. In general, it is a clayey silt or silty clay, but in some localities it is very sandy. Loess characteristically stands in steep faces. It is usually thickest near and inland from the bluffs of the Mississippi and Illinois Rivers, especially on the east sides, and along the Ohio River. On the bluffs facing the rivers it may be 50 feet or more thick.

In the unglaciated areas (fig. 24), clay that is a residue left from the solution of limestone or dolomite by weathering overlies many limestone or dolomite deposits. The clay is brown, reddish brown, red, or yellow, and contains chert in some places. Its thickness varies; in northwestern Illinois it probably is generally less than 5 feet thick, and in extreme southern Illinois the average thickness does not usually exceed 15 feet. The residual clay is most often overlain by loess. The limestone or dolomite surface on which

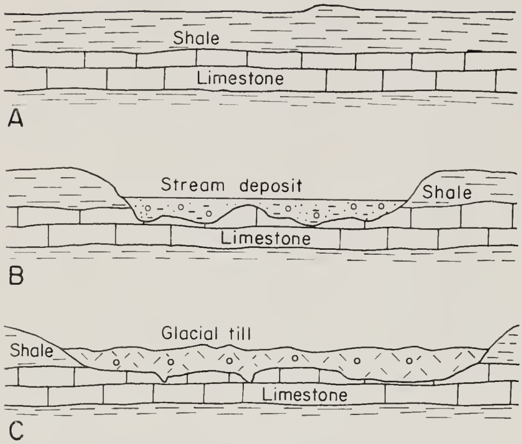

FIG. 25—Idealized drawing showing (A) a thin limestone deposit overlain by shale, (B) the same deposit after erosion by a stream that left a deposit of alluvial silt, sand, and pebbles as overburden on the limestone, and (C) the original deposit (A) after erosion by a glacier that left a deposit of pebbly clay (till) upon the limestone.

it rests may be very uneven and characterized by valleys, ridges, and spires.

Unconsolidated deposits of Cretaceous-Tertiary age are found in the southernmost part of the state (fig. 24) resting on bedrock and are covered by loess. The deposits include clay, silt, sand, and gravel and vary greatly in thickness, reaching more than 100 feet in places.

Shale or Sandstone Overburden and Limestone Thickness

As shale or sandstone overburden is usually more difficult to remove than unconsolidated materials, few limestone deposits with much consolidated cover are worked by open pit in Illinois. However, in certain instances shale, underclay (fireclay), or sandstone overburden on a stone deposit may have a significant relation to the thickness of the stone. The relation is especially important for the relatively thin Pennsylvanian limestones.

As stated previously, all the commercial limestones and dolomites of Illinois were originally deposited in oceans and other materials were laid down on top of them. If these materials were clay or sand, they have since been hardened into shale or sandstone, and the presence of these rocks as overburden on a limestone or dolomite deposit may indicate that the full original thickness of the limestone or dolomite is present. However, when a limestone or dolomite deposit does not have a shale, sandstone, or other bedrock overburden, this overburden, and possibly part of the limestone or dolomite, has been removed by some means. Any overburden of unconsolidated materials now on the deposit has been laid down since the shale or sandstone overburden was removed.

The shale or sandstone was most likely removed by stream erosion or, less commonly, by erosion by glaciers as suggested by the planed and scratched surfaces of some deposits. Neither of these kinds of erosion necessarily stopped when the top of the limestone or dolomite deposit was reached. Hence, the limestone or dolomite may be less than its original thickness (fig. 25). Usually the last eroding agent can be identified by the kind of

unconsolidated overburden that covers the deposit. If the overburden is till, the agent probably was a glacier, and if it is silt, sand, and gravel, the agent probably was a stream. It is possible, however, that after a stream had eroded the shale or sandstone overburden from a deposit, the deposit could have been planed down by a glacier. The reverse is also possible.

The upper surfaces of some eroded deposits are reasonably even, others are much channeled and uneven. If a limestone deposit 100 feet thick is being quarried, irregularities having a vertical height of 10 feet in its upper surface are not necessarily a limitation to its development, but if the limestone is only 10 to 15 feet thick, a 10-foot irregularity could be a serious handicap. Therefore, the character of the overburden and its relation to irregularities in the top of many of the relatively thin Pennsylvanian limestones is a significant matter.

Water in Limestones and Dolomites

Kinds of Water in Rock

Water in limestones and dolomites occurs in two major ways, (1) in readily visible amounts that seep or flow along joints or bedding planes or flow in channels or tunnels through the stone, and (2) scattered in minute pores throughout the rock. Water occurring in the first manner is here called visible water and is usually the quarryman's greatest problem, either by reason of its presence or the fact that it once was present. Water occurring in pores is sometimes called pore water or quarry sap.

Source of Water

The visible water encountered in present quarries probably comes, for the most part, from (1) rain or snow water that soaks into the surficial materials overlying the rock strata at or in the general vicinity of the quarry and moves through joints or channels in the stone, or (2) from rain or snow water that first enters sink holes and then moves underground through channels.

The sink holes and underground channels through which the water moves may be quite ancient. The sink holes were formed when solution produced underground openings in the limestone, and the roofs of these openings subsequently collapsed (fig. 26). Therefore, an area that contains sink holes indicates the probable presence of an underground drainage system of channels of various sorts. An attempt to shut off an underground stream of water in a quarry or mine by blocking one or several sink holes in the vicinity is likely to be unsuccessful because the underground drainage passages probably are interconnected and carry water that enters by many sink holes, some of which may be far from the place where the underground stream is encountered.

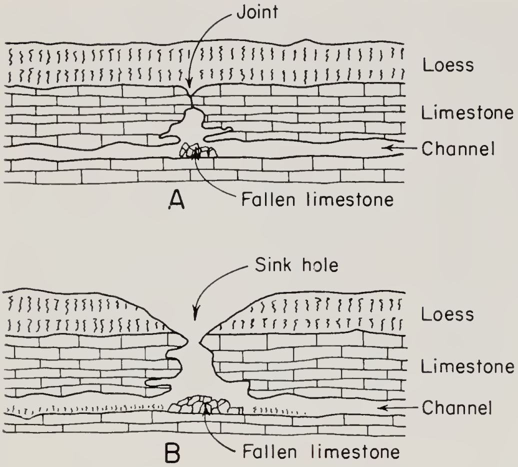

FIG. 26—Diagrammatic cross section showing one way in which a sink hole may form in a limestone deposit having a loess overburden. A loess cover is a common condition in many places where sink holes are found in Illinois. Sketch A shows an underground stream channel and a cavity developed in the limestone deposit that has a pronounced vertical joint. In sketch B the solution has enlarged the joint, the roof of the cavity has collapsed, and loess has washed down into the channel and been carried away by the stream to produce a sink hole.

Development of Underground Watercourses

The joints in limestone and dolomite deposits allow water to seep slowly along them, and the resulting gradual solution of the rock causes the formation of an opening or a watercourse for visible water to follow. Attempts to avoid water-bearing joints in quarrying should take into consideration the fact that most limestone or dolomite deposits in Illinois have more than one set of joints and, whereas the underground water may in general follow one set, it may also at times follow a second set and pursue a zig-zag course through a deposit.

Bedding planes constitute another avenue along which water can seep and in time develop underground openings, including caves and tunnels. In some places solution of the limestone along a bedding plane produces very irregular projections in the upper limestone bed that fit into depressions in the lower bed and vice versa. Such a bedding plane is referred to as a stylolite or "crowfoot" (fig. 27) and is quite evident when viewed at right angles to the bedding of the limestone. As the limestone was dissolved, its impurities usually remained along the stylolite. In many limestones these impurities are black. Stylolites are more common in Illinois limestones than in dolomites.

The openings produced along joints or bedding planes vary both in width and height from place to place. The amount of variation depends on the purity of the limestone, on its texture and porosity, on possible variations in the volume of ground water flowing along the subterranean channels, or on changes in the capacity of the water to dissolve limestone.

Abandoned Underground Watercourses

The same features that characterize active underground watercourses characterize abandoned watercourses through which water no longer flows. Many of them are more or less filled with clay, silt, or sand carried into them by water. Those near the surface of a stone deposit may be completely filled

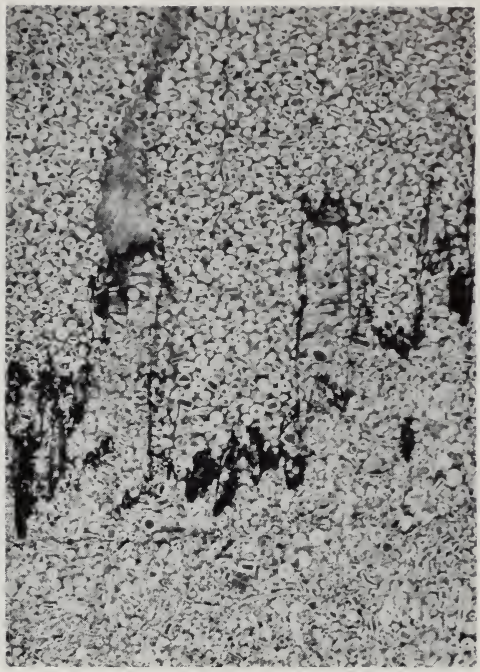

FIG. 27—Stylolite (or crowfoot) in oolitic limestone from Anna. The oolite above the stylolite is coarser grained than that below it. Polished surface. Enlarged 2 times. Ste. Genevieve Limestone.

with sediment. No special study has been made of these channel or cave filling materials, but along the Mississippi, Illinois, and Ohio Rivers they are believed to be predominantly brown or red silty clay; in the greater Chicago area the fillings are often greenish gray clay. The fillings, as may be anticipated, often follow or align themselves with the major joint systems in a deposit, although locally they may follow a secondary set or sets of joints.

Time of Formation of Caves and Watercourses

Most of the caves, tunnels, and underground watercourses in Illinois limestone deposits are believed to have been formed many years before the present topography of Illinois existed. At various stages in their history the openings have been more or less filled with clay, silt, and other earth materials. These fillings either have been or now are being removed from the older caves and some enlargement is occurring (Bretz, 1961, p. 1).

Relation of Watercourses to Quarrying or Mining

In assessing the commercial possibilities of a limestone or dolomite deposit, especially if it is more than about 10 feet thick, the possible presence of active or abandoned underground watercourses should be considered.

The presence of springs or the occurrence of sink holes in such numbers that they constitute the only means for rain or snow water to drain away, suggests that water-bearing or dry channels and openings probably exist in the deposit.

Pore Water

Pore water, sometimes called quarry sap, is likely to be of commercial significance only to quarries that contain a great many springs or those that produce building or decorative stone. Freshly quarried building or decorative stone is usually allowed to dry out before processing. If the stone is not allowed to dry, its durability is said to be adversely affected when it is exposed to the weather. The quantity of pore water in the stone of Illinois quarries that produce crushed stone is not known to be of importance.

The amount of water occurring between the grains of limestones and dolomites, or as inclusions within the grains, is indicated by the data from chemical analyses which gave the percentage of water evolved when samples are heated for an hour at 110°C (230°F). Data for many samples of Illinois limestones and dolomites that had been kept dry for a matter of weeks or months before they were analyzed, indicate a most common water content of between 0.01 and 0.10 percent by weight. About 10 percent of the samples gave off no water, whereas approximately 10 percent gave off more than 0.25 percent water. The average amount of water evolved from the limestones was 0.12 percent, the same as the average for dolomites.

Efflorescence

Efflorescence is a fine-grained, powdery deposit formed on the surface of a stone as a result of the evaporation of water from within a stone containing dissolved mineral materials. Its development is facilitated by any conditions that favor the seepage of moisture through a stone. It is occasionally seen on exterior limestone or dolomite building stones. Gypsum is a common efflorescence and sodium chloride and calcium sulfate subhydrate also have been noted (Lamar and Shrode, 1953).

Case Hardening

Some comparatively soft, porous Illinois limestones, especially those composed of fossil debris, develop a hardened exterior when exposed to the weather. This is believed to be the result of the movement of calcium carbonate from within the stone to its surface by pore water, rain, or snow water. When the water evaporates, the calcium carbonate is deposited at the surface of the stone, making it harder. The process is called case hardening, and the stone is said to be case hardened. Many case hardened limestones have a greater weather resistance than they had originally.

Physical Features Related to Quarrying and Use

A number of physical characteristics of limestone and dolomite deposits, such as the thickness of the beds, presence of joints, dip of the strata, and thickness variations, bear on their quarrying and utilization.

Bedding

The limestone and dolomite deposits of Illinois occur in beds or layers of different thicknesses, the formation of which has already been described. Although most deposits are made up of strata of various thicknesses, one thickness—thin, medium, or thick—usually predominates. Some deposits are therefore said to be thin bedded, others thick bedded, heavy bedded, or massive. There are no generally accepted limits defined for these terms and their use is relative, depending on the character of the deposit in question. For example, a 15-inch bed might be considered thick in a deposit composed mostly of 2- to 4-inch strata, but it would be of only medium thickness in a deposit composed of 12- to 24-inch layers. The following classification of bedding thickness has been proposed recently by Templeton and Willman (1963, p. 22) and probably approximates general usage in Illinois.

Very thin bedded	less than 1 inch thick
Thin bedded	1 to 3 inches thick
Medium bedded	more than 3 inches and less than 12 inches thick
Thick bedded	1 to 3 feet thick
Very thick bedded	more than 3 feet thick

In underground limestone mines in Illinois thin beds are commonly avoided as roofs, presumably because they are more likely to slab off or spall than are thick-bedded strata. However, in the quarrying of stone for flagging, curbing, and building stone, thin- to medium-bedded deposits often are preferred, and many deposits of limestone and dolomite having these characteristics have been worked in Illinois, especially in earlier days when the quarrying and dressing of the stone was done by hand.

When building stone is used so that the exposed surface is a natural bedding plane, or is parallel to such a plane, it is said to be "bed faced." If it is used so that the exposed surface is approximately vertical to the bedding of the stone, it is described as "edge faced." Some limestones and dolomites split with equal ease in all directions because they have a very uniform texture and are called "free working" stones or freestones. Many such stones give good service regardless of how they are faced. They commmonly come from deposits that are thick or very thick bedded. On the other hand, some stone from thin- or medium-bedded deposits, particularly the former, may spall along bedding surfaces and hence is likely to have greatest durability if edge faced.

Dipping Strata

The limestone and dolomite in Illinois were deposited in flat layers, with the exception of certain deposits mentioned later. The layers that are not now flat have been tilted by warping of the earth's crust. Hardly any rock strata of Illinois now lie flat but generally dip in one direction or another even though the dip may be very gentle.

Within a given quarry it is probable that the limestone or dolomite strata have a major direction of dip, although there may be variations in the rate of dip or even in its direction from place to place. The dip of stone strata has a variety of effects on quarrying, some of which are shown in figures 28, 29, 30, and 31.

A map showing in detail how the rocks in the state dip would indicate numerous upfolds and downfolds in the rock strata (fig. 23). Many of these folds are comparatively small but others extend for miles. The rate of dip of the rocks in some places may be more than 1000 feet to the mile, whereas in others it may be only a few feet per mile. Many Illinois rocks dip 200 or 300 feet per mile.

The major upfolds in Illinois, or anticlines as they are known technically, are shown in figure 23. Between the anticlines the rocks generally are downwarped, and these downfolds are called synclines. They vary greatly in size. Fold A is a monocline, in which the beds are folded in roughly the same way as carpet when it is bent to fit a tread of a stair, the riser below it, and the next lower tread.

The Silurian dolomites in northeast Illinois consist, in places, of dipping layers that are not related to folding but rather are deposits made on

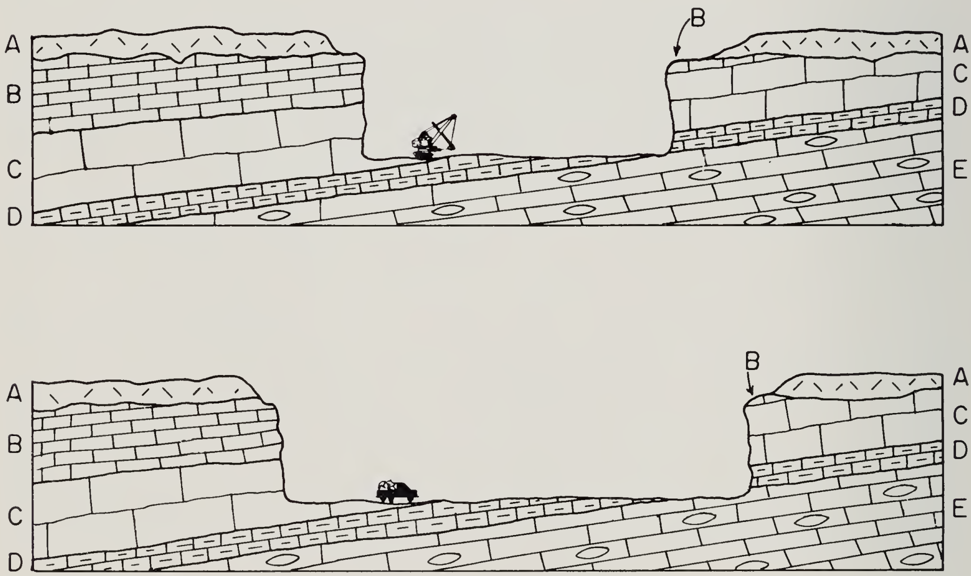

FIG. 28—A quarry operating with a level floor in a deposit composed of dipping strata (top drawing). A is unconsolidated overburden, B is thin-bedded limestone, C is thick-bedded, high-calcium limestone, D is thin-bedded, shaly, impure limestone, and E is medium-bedded cherty limestone. Because of the dip of the strata, the shaly, thin-bedded limestone (D) is present in the right face but does not appear in the left face. The purity and physical properties of the crushed stone from the two faces will be unlike.

In the lower figure the quarry has been enlarged both to the left and right, and as a result the high-purity stone (C) is thinner in the left face, whereas unit B is thicker. In the right face, only a sliver of unit B remains and the cherty bed (E) appears at the bottom of the quarry face.

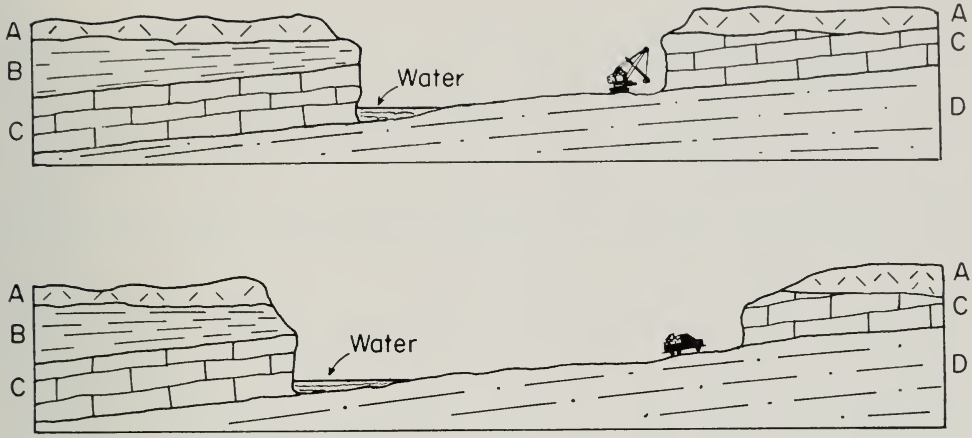

FIG. 29—The top drawing shows a quarry operating in a comparatively thin, dipping limestone bed; the floor of the quarry follows the base of the limestone. A is unconsolidated overburden, B is shale, C is limestone, and D is sandy shale. Any water in the quarry collects at the working face at the low side of the pit. In the expanded quarry shown in the lower figure, the thickness of the shale overburden has increased in the left face; the thickness of the limestone in the right face has decreased. The thinning of bed C to the right illustrates one of the ways in which limestone formations "pinch out."

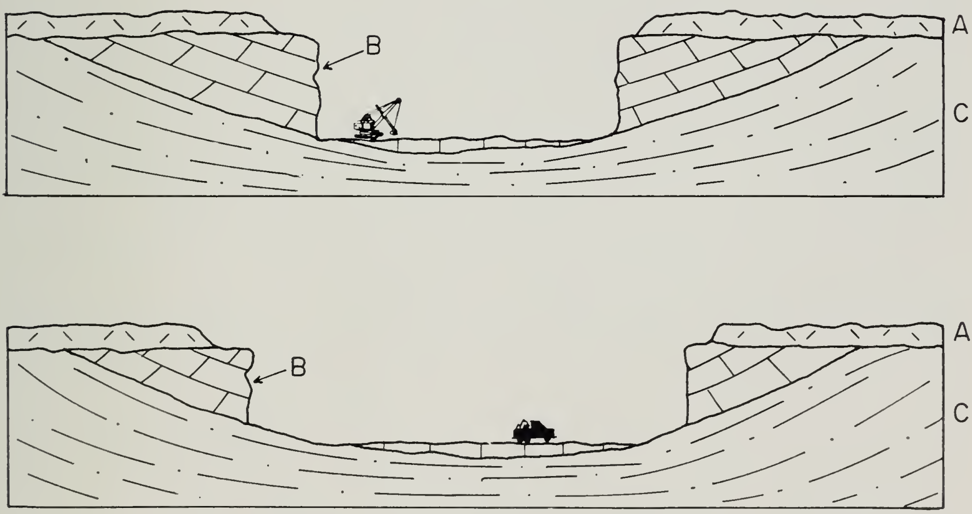

FIG. 30—A quarry with a level floor located in a downfold, or syncline, having a limestone bed in its center. A is unconsolidated overburden, B is the limestone, and C is sandy shale. In the lower drawing, the quarry has been enlarged and the height of the base of the limestone above the quarry floor has increased. The thinning of bed B both to the left and right indicates one way in which a deposit "pinches out."

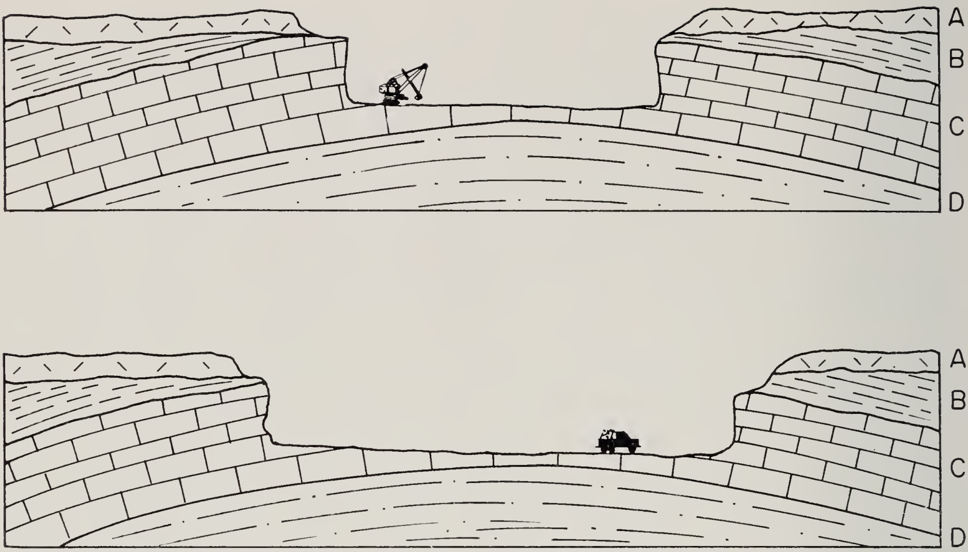

FIG. 31—A quarry with a level floor located in an upfold, or anticline, in the center of which a limestone bed is exposed. A is unconsolidated overburden, B is shale, C is limestone, and D is sandy shale. In the enlarged quarry (lower drawing), the thickness of the shale overburden has increased, the limestone in the quarry face is thinner and will continue to thin unless the quarry floor is lowered. Expansion of the quarry in either direction would be accompanied by an increase in the amount of shale overburden on the limestone.

the flanks of ancient reefs composed of corals and other fossil materials. Figure 32 shows how these deposits were formed.

Still another type of dipping limestone bed not caused by folding of the rock strata is known as cross-bedding (fig. 33). It usually is restricted to limestones that are made up principally of small particles, such as fragments of fossils or oolite grains. Cross-bedded limestones were originally deposited in the same way as a sand, and the inclination of the layers results from the building of a delta, a bar, or a similar deposit by ocean currents.

In the technical description of dipping strata, the terms dip and strike are often used. The strike of a bed is the direction of a level line along its surface. If a body of water, such as a puddle, can be found in contact with a dipping bed, the line of contact of the water and the bed is the line of strike

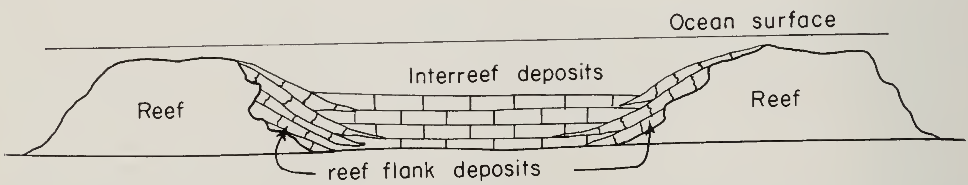

FIG. 32—Two reefs with inclined reef flank deposits and flat-lying interreef deposits.

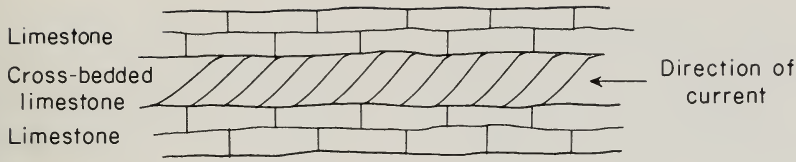

FIG. 33—Cross-bedded limestone stratum between two flat-lying limestone beds. The direction of the current that formed the cross-bedded layer is shown.

(fig. 34). A level also may be used to find the direction of strike. The direction of strike of a bed is expressed in terms of departure from a north-south line (fig. 34).

The dip of a bed is its maximum inclination from the horizontal and is measured at right angles to the strike (fig. 34). It is expressed in degrees. The symbol used to indicate dip and strike on maps is shown in figure 34. A number near the arrow of the symbol indicates the amount of dip in degrees. One degree of dip is equivalent to 92 feet per mile. In written descriptions the direction of dip is specified. For example, in figure 34 the dip of the bed in A is 25 degrees to the southeast, and is written 25° SE.

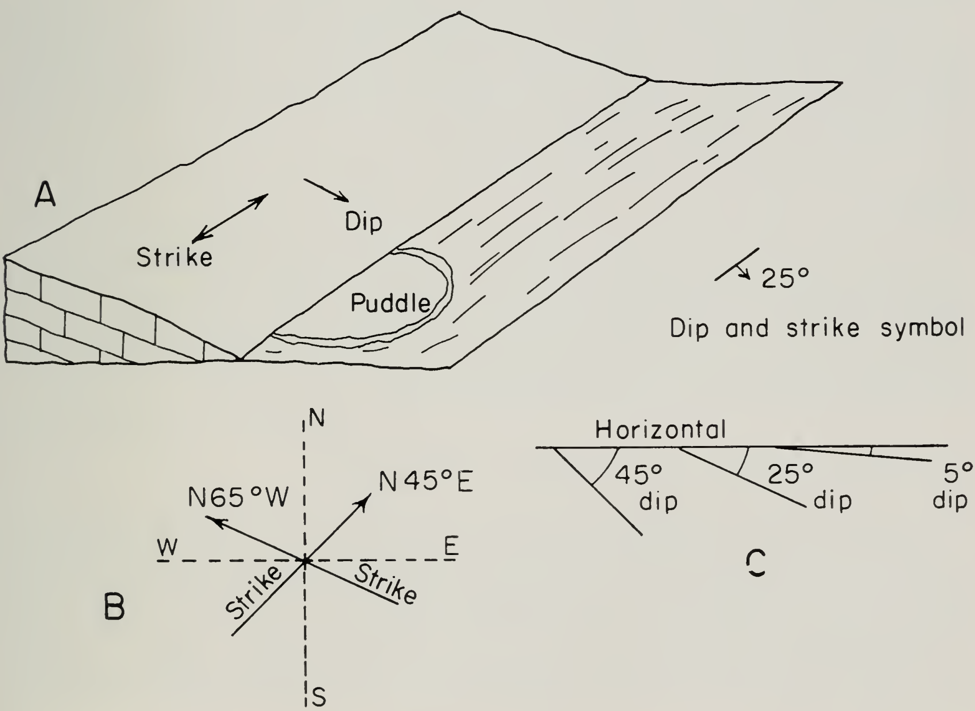

FIG. 34—Sketch A shows the dip and strike of a rock stratum and also how the edge of a puddle parallels the strike where it meets the dipping stratum. B shows two directions of strike and the terms used to describe them. C illustrates three different dips and how they are measured.

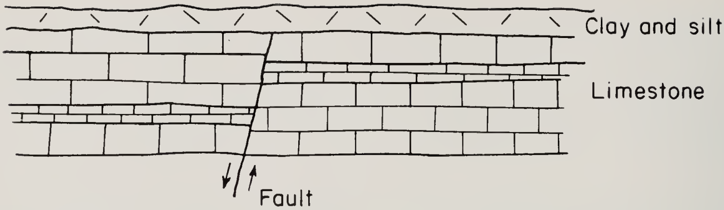

FIG. 35—Sketch of a normal fault. The strata on the right of the fault have moved up with reference to those on the left.

Joints

A joint is a fracture or crack in a rock deposit that has resulted from breakage due to stresses and forces in the earth's crust. Most joints in Illinois rocks are vertical, or nearly so, but some are inclined at an angle.

In most limestone and dolomite deposits the joints occur in "sets." One set of joints may follow a north-south direction, another a northwest-southeast direction. One quarry may have only one set of joints, another may have one major set and one minor set, and still another two or three major sets and no minor sets. Various combinations of sets of joints are common.

Joints are common avenues along which ground water flows, as has been previously discussed, and depressions in the top of a limestone or dolomite deposit may be largely localized along joints and hence tend to follow along the direction of one or more sets of joints.

Faults

A fault is a fracture or a group of fractures along which there has been actual movement of the rock strata. Faults are not commonly found in Illinois quarries; the movement along those that occur has been no more than a few inches or a few feet. They are generally vertical or nearly so and are known as gravity or normal faults (fig. 35).

Relation of Folds and Faults to Outcrops

Limestone and dolomite deposits are essentially flat-lying when they are formed in the sea. If they are not disturbed by folding or other earth movements they will continue to be flat-lying after the sea withdraws and they become land. Where they crop out will depend largely on how the land surface has been eroded and the distribution of overburden. Figure 36 shows the effect of erosion on horizontal bedrock strata and the kind of outcrop areas that result.

In some parts of Illinois the limestones and dolomites are so nearly flat-lying that they more or less follow the pattern shown in figure 36. In many places in the state, however, the bedrock strata dip gently or are gently

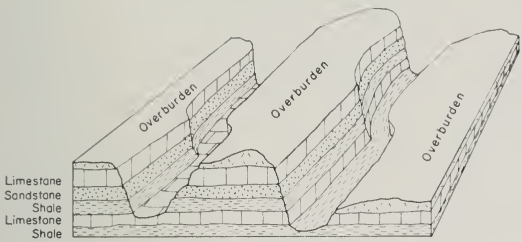

FIG. 36—Horizontal strata cut into by streams. Outcrops occur as linear bands along the walls of stream valleys and are continuous, except where the stratum is obscured by overburden. Where a limestone formation underlies an unconsolidated overburden, as does the top limestone in the figure, large open pit quarries are possible. If the limestone has a considerable thickness of bedrock above it, as is true of the lower limestone in the sketch, underground mining may be necessary.

folded as a result of slowly acting natural forces in the crust of the earth. Locally the rocks are broken by faults.

Figure 37 illustrates the effect of dipping strata on areas of outcrop. It applies especially to outcrops in the bluffs of streams, such as those along the Mississippi and Illinois Rivers. As a dip of only 1 degree, which is so small that it is often difficult to recognize in a single outcrop, will lower a bed about 90 feet per mile, it is evident that the dip of a limestone bed can have an important relation to its area of outcrop.

The effect of downfolds on the distribution of areas of outcrop is shown in figure 38A. Only the limestone in the central part of the downfold remains; erosion by streams and other natural forces has removed the rest of the original limestone stratum. In a case of this sort, the thickness of the limestone stratum decreases near the edge of the deposit. Test drilling around the deposit obviously will not encounter additional deposits of the stone.

Figure 38B shows an eroded upfold that exposes a limestone stratum at its crest. The deposit thickens toward its margin. Drilling around the margin of the outcrop area will encounter limestone, but shale overburden will be present and will increase in thickness with distance from the outcrop area.

The effect of a fault on the occurrence of limestone is shown in figure 38C. An area underlain by limestone occurs on the left, or downthrow, side of the fault. The limestone rests on shale. On the right, or upthrow, side of the fault, the limestone has been completely worn away and only the shale that underlies it crops out.

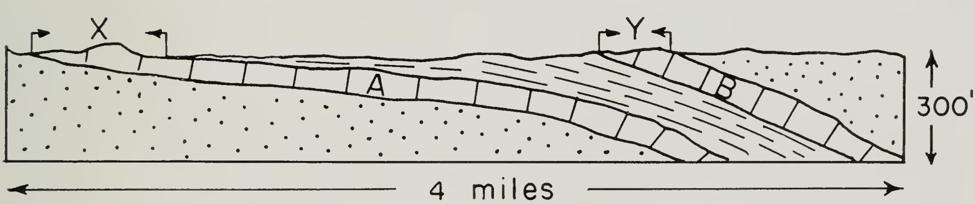

FIG. 37—Longitudinal section of a river bluff showing how the dip of a limestone formation may cause it to crop out near the top of the bluff at some places and at the base at others. Even though limestone beds A and B are of about the same thickness, the area at X where limestone bed A might be quarried by open pit is wider than that of bed B at point Y because the latter bed has a steeper dip.

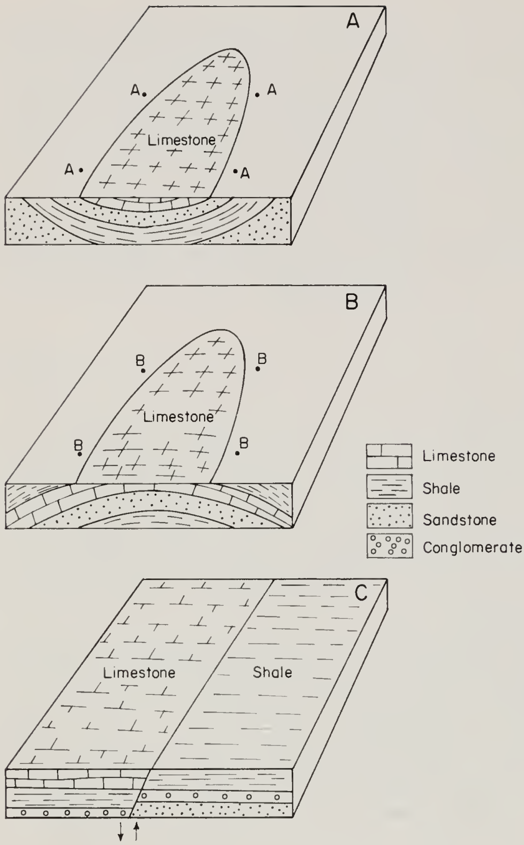

FIG. 38—Sketch A shows one end of a spoon-shaped downfold or syncline that has been eroded to expose a limestone stratum. If borings were made at the points marked A, they would not find limestone.

Sketch B shows one end of an upfold or anticline, shaped somewhat like an upside-down spoon, whose upper part has been eroded to expose a limestone stratum. If borings were made at the points marked B, they would first penetrate the shale that overlies the limestone and then the limestone itself.

Sketch C shows a fault. The rocks on the left side of the fault have moved down and those on the right side have moved up. Erosion has exposed a limestone stratum on the left side of the fault but has removed the limestone on the right side and exposed the shale that underlay it.

Obviously, the illustrations given are greatly simplified and exaggerated compared to actual occurrences of limestone, which are usually more complicated owing to, among other causes, irregularities in the land surface. The examples do, however, explain some of the factors, excluding overburden, responsible for the presence or absence of outcrops of limestone-bearing strata in Illinois.

Character of Top of Stone Deposits with Unconsolidated Overburden

The effect of a shale or sandstone overburden on the thickness of deposits and on the character of the top of a limestone or dolomite has already been discussed. The character of the top surface and upper part of limestone or dolomite deposits having an overburden of surficial materials—silt, clay, sand, or gravel—involves some of the same phenomena. A primary concept is that at one time every limestone or dolomite deposit in Illinois had on it an overburden of bedrock materials. Removal of these materials was accomplished primarily by running water or glaciers.

The eroding action of running water, in the form of streams or slope wash, is well known. Even within a small area it characteristically is more extensive in some places than in others, so that a surface thus eroded is likely to be uneven. The top surface of most Illinois limestone and dolomite deposits from which bedrock overburden has been worn away by running water is of this nature under the surficial materials that are the present overburden. A combination of erosion and solution by running water very often enlarges joints and cracks in the surface of deposits, and other irregularities related to the porosity or composition of the rock also develop.

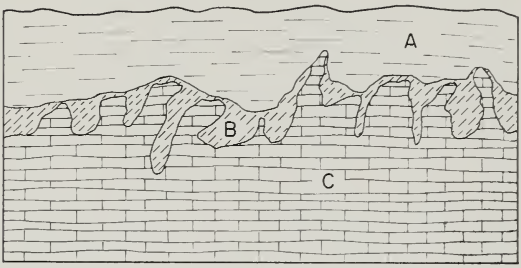

FIG. 39—Limestone deposit (C) that has an irregular surface because of solution. A red, brown, and yellow clay (B) rests on the stone and is the residue from the limestone that has been removed by solution. The overburden (A) is clayey silt.

In the unglaciated areas of southern, western, and northwestern Illinois (fig. 24), another factor has influenced the character of the bedrock surface—the fact that for thousands of years it has been subjected to weathering and accompanying solution by rain and snow water. As a result, the bedrock is at many places immediately overlain by red, brown, or yellow clay, which is often cherty (fig. 39). This clay originally occurred as an impurity in the strata of limestone or dolomite that through the years have been dissolved away. The rock that was dissolved was tens, if not hundreds, of feet thick in some places. The surface of the stone in many deposits of this kind is very irregular and cut into sharp ridges and spires (fig. 39). Joints in the stone have influenced the development of the irregularities, as have differences in the stone's porosity and composition. In stripping such deposits some quarry operators discard all, or most, of the irregular top stone as overburden.

The effect of glaciers on limestone and dolomite deposits was both undesirable and beneficial. Usually the glaciers left behind them a deposit of pebbly clay or silt, or, locally, sand or gravel, that constitutes the present overburden. In some places it is likely that bedrock materials were removed from limestone deposits by glacial action. In the northern and northeastern part of Illinois the ice appears to have rounded off the bedrock surface and scoured away much of the debris and residual materials that had been formed by weathering before the arrival of the ice. Scratches found locally in the top of the bedrock record the abrasive action of the glacier ice.

In the greater Chicago and Kankakee areas, some of the tracts underlain by reef-type dolomite now appear as broad, rounded hills, either because they resisted glacial scour better than other types of dolomite in the areas or because they had superior weather resistance and hence were less deeply weathered before the glacier arrived than the adjoining nonreef dolomite.

In the western part of northern Illinois, the surficial parts of some dolomite deposits are broken down into their component crystal grains to form a yellow or brown dolomite sand 10 or more feet thick. Pieces of loosely coherent dolomite that break down readily to a sand are present in many deposits. Such deposits have limited commercial possibilities and are mostly used as sources of agricultural limestone. Weathering probably caused the actual disaggregation of the dolomite. The color of the deposits is due to iron oxide.

Although glacial erosion planed off some of the pre-glacial irregularities in the surface of limestone and dolomite bedrock, it does not appear to have materially altered other features. In the dolomite-bearing area of northeastern Illinois, roughly circular, elongate, or irregularly rounded depressions of various sizes appear locally in the surface of the dolomite and are either sink holes (Ekblaw, 1924) or, possibly, pot holes developed in the bed of some ancient river. Athy (1928, p. 62) found the walls of some of them ". . . are smooth and polished and show evidences of wear." Many of the depressions are developed along joints, and joints that have been enlarged by water are present in places. A small cave whose roof had collapsed was once visible in a quarry near Kankakee. Phenomena of the various types mentioned have been observed principally in the Kankakee and Joliet areas, but they no doubt occur at other places.

The enlarged joints mentioned above are filled with greenish gray clay, as are some of the depressions; other depressions contain black clay and other materials as well. One depression near Kankakee contained strata that have been identified as of Pennsylvanian age; no other Pennsylvanian strata are known in the immediate vicinity. The clay in a depression near Joliet contained fragments of chert and silicified fossils. The clay fillings may be entirely or in part a residuum from the solution of dolomite bedrock.

Lateral Variations

The changes that occur in limestones and dolomites from one place to another are known as lateral variations. They include variations in thickness, chemical composition, hardness, weather resistance, and similar matters. Basically, lateral variations in limestones and dolomites are, in large part, the result of changes in the character of the material deposited in the oceans in which the rocks were formed, or of changes in some characteristics of the ocean itself. For example, if a limestone is made up of fossil debris at place A but is very fine grained at place B, it is likely that at A there was an abundant population of shell fish whose hard parts were deposited as a "shell sand," whereas at B shell fish existed in small numbers, if at all, and conditions favored the deposition of lime mud.

Another type of lateral variation includes changes in the thickness of individual beds in deposits. In some deposits, certain strata maintain a relatively uniform thickness for hundreds of feet, whereas other strata

thicken, thin, or even pinch out completely within short distances. The uniform strata indicate stable conditions of deposition in the ocean in which they were formed, whereas strata of variable thickness are likely to be the result of variable conditions.

The variation in thickness of a limestone or dolomite formation that has an overburden of other bedrock usually is a function of the variation in the thickness of the strata that compose it, as mentioned above. In some cases the thickness may vary, however, because the limestone or dolomite deposit was raised above the sea in which it was formed and parts of it worn away by ancient streams. Thereafter it was again submerged beneath the ocean and other deposits laid down on it that now constitute its bedrock overburden.

Lateral variations in the thickness of a limestone or dolomite formation that has an overburden of unconsolidated materials may be partly the result of a difference in original thickness. However, such variations, especially local ones, are most likely to be related to erosion of the top of the deposit by running water before the overburden was deposited.

Variations in purity also are commonly related to changes in ocean conditions. Pure limestone or dolomite is likely to have been formed in an ocean in which no mud or sand was being brought from surrounding land. An impure limestone or dolomite suggests opposite conditions. Lateral variations in the amount of chert may result from variations in the original distribution of silica in a limestone or dolomite.

The extent to which some limestone formations have been altered to dolomite is another characteristic that varies laterally. It is related to the extent to which the change took place while the limestone was still beneath the ocean or, possibly, to later changes resulting from the introduction of magnesium into a limestone formation by ground water.

Lateral Variations in Illinois

Lateral variations of all the kinds mentioned above occur in the limestones and dolomites of Illinois. Some take place within a few hundred feet, others in a matter of miles. For example, in northwestern Illinois there is a thick dolomite known as the Galena Dolomite, and in southern and southwestern Illinois there is a thick limestone known as the Kimmswick Limestone. The major part of the dolomite is considered to be about equivalent in age to the limestone. This lateral variation is characterized by a difference in chemical composition.

Many of the Pennsylvanian limestones vary laterally in thickness. Because these limestones are relatively thin, this variation is more noticeable than it would be if the formations were thicker. The Omega Limestone in south-central Illinois is ordinarily 3 to 4 feet thick and of moderately good purity. In places, however, it may be more than 15 feet thick. This increase in thickness is due in part to an increase in the amount of silt and clay present, and as a result the thicker Omega Limestone is generally less pure than the thinner phase; some of it is very impure. A roughly similar phenomenon

characterizes the Brereton Limestone, which is the caprock of the Herrin (No. 6) Coal, in southern Illinois. In northern Illinois the LaSalle Limestone at LaSalle is 20 to 30 feet thick, but about 10 miles to the west the limestone thins to about 8 or 10 feet.

Clay or Shale Beds

A thick shale or clay layer in a limestone or dolomite deposit obviously poses a number of problems because it is chemically and physically unlike the stone. Both shales and clays become sticky when wet and for this reason may hinder quarrying or crushing. They also may affect blasting procedures. In concrete aggregate, agricultural limestone, and other such stone products, clay and shale are considered undesirable materials. However, a certain amount of clay or shale mixed with crushed stone yields a product that is used for making stabilized roads.

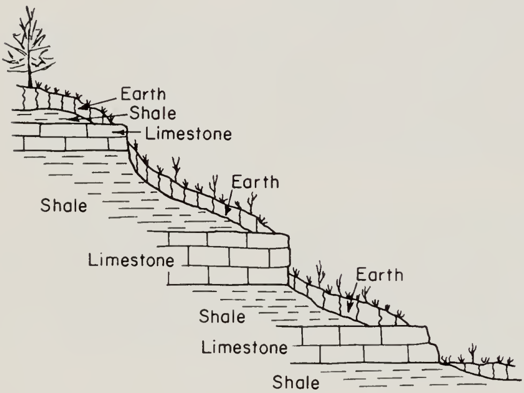

FIG. 40—Cross section of a hillside in which ledges of limestone or dolomite crop out at intervals and are separated by slopes covered with earth and vegetation. The diagram shows how shale interlayered with limestone or dolomite beds can produce such an outcrop. Hillsides like this should be carefully inspected for shale and should not be assumed to consist of a continuous deposit of limestone or dolomite.

The chemical composition of the clays and shales occurring in limestone and dolomite deposits varies, but they often contain limy material that occurs either finely mixed with the clay and shale, as granular masses, or as thin, interbedded layers of limestone or dolomite. The presence of clay or shale reduces the calcium carbonate equivalent of agricultural limestone. Take, for example, a quarry producing agstone from a uniform limestone 10 feet thick that has a calcium carbonate equivalent of 85 percent. A 1-foot thick bed of shale having a calcium carbonate equivalent of 25 percent is encountered in the quarry face and takes the place of a foot of limestone. When the shale is included with the limestone, the calcium carbonate equivalent of the agstone from the quarry drops to 79 percent.

Some thin limestones in Illinois are divided into two or more benches by clay or shale beds. In the quarrying of such deposits, either the clay or shale must be included with the quarry product or the limestone strata must be quarried separately. To lessen the effect of the shale and clay on agstone and other grades of stone, attempts are sometimes made to concentrate these materials in a particular size grade during crushing. One procedure involves scalping the throughput of the primary crusher on a vibrating screen that has

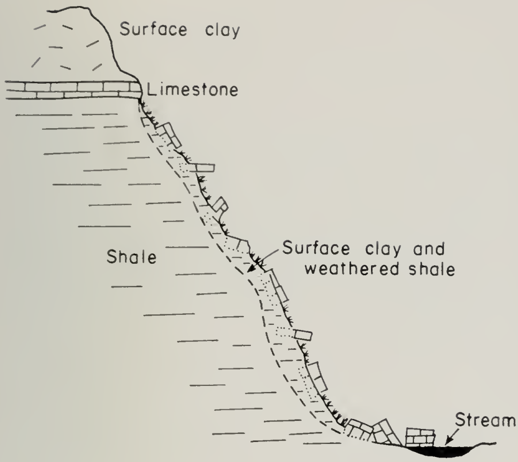

FIG. 41—Blocks of limestone that have slumped from a thin limestone bed near the top of a bluff, made up mostly of shale, and have lodged in the face of the bluff and in the stream bed at its base. Such a distribution of limestone blocks is sometimes interpreted to mean that a continuous limestone bed extends from stream level to the limestone ledge at the top of the bluff. The situation shown by the sketch is often more probable.

openings of about one inch. Unless the clay or shale is wet, it is probable that a considerable amount of it will have broken into pieces smaller than much of the stone. The clay or shale is thus likely to fall in the minus 1-inch category, and as a result the plus 1-inch stone will have a reduced clay or shale content.

The presence of clay or shale beneath a limestone or dolomite deposit in some cases requires that a basal layer of stone be left to insure a quarry floor that will permit all-weather traffic. Otherwise, stone-surfaced roadways must be constructed. If a quarry has a clay or shale floor and the chemical composition of the crushed stone produced is critical, care must be taken during loading of the stone not to pick up clay or shale to avoid contaminating the stone.

Such problems make it important to determine whether clay or shale beds occur in a potential quarry site.

In the search for or inspection of sites, hill slopes in which are exposed a series of limestone ledges separated by earth-covered areas often overgrown by vegetation should be considered questionable. Such a situation may be like that drawn in figure 40, which shows a deposit consisting of limestone ledges separated by beds of shale. Although the hill slope at first glance might be thought to be composed entirely of limestone, its true nature is quite different. Test drilling or trenching is desirable, therefore, to determine whether deposits contain clay or shale beds.

Clay and shale are also responsible for slumping, which can give a false impression of the thickness of a limestone or dolomite formation (fig. 41). Blocks of a jointed limestone or dolomite stratum that is underlain by clay or shale can slump and slide down a slope when the clay or shale becomes wet and plastic and slippery. The presence of blocks of limestone at intervals on the face of a bluff and in the stream bed below is sometimes interpreted to mean that a continuous limestone or dolomite stratum extends from stream level to the topmost outcrop. Figure 41 shows that the true situation may be different.

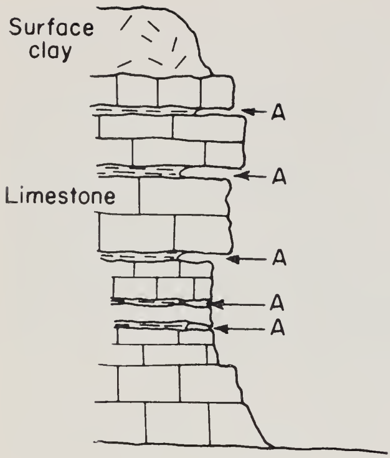

FIG. 42—Cross section of a limestone outcrop that contains clay or shale beds, indicated by the letter A. The clay or shale has been washed out by rain or spalled out by weathering, leaving notches in the outcrop. Failure to include the clay or shale during sampling will yield a sample that will not represent the true chemical and physical character of the commercial product that would be quarried from the outcrop.

The weathering characteristics of limestone or dolomite outcrops containing thin beds of interlayered clay or shale also merit mention. In natural outcrops and older quarry faces, small gaps often are present in the vertical continuity of the rock exposed. These frequently are caused by the weathering out of thin layers of clay or shale. Such layers commonly are considerably less resistant to the destructive effects of the weather than is the rock with which they are interbedded. They may therefore weather back from the rock face for several inches, with the result that their presence may be obscured (fig. 42). Weathering of the limestone or dolomite deposit itself may then be speeded. The presence of numerous slabs of stone at the foot of a limestone or dolomite exposure is sometimes an indication of the presence of interbedded clay or shale. In sampling deposits of this type, it is important not to overlook the clay or shale beds and sample only the limestone or dolomite.

Clay and shale are not readily penetrated by water and hence tend to restrict the downward movement of ground water through limestone or dolomite deposits having clay or shale beds in them. In some areas, particularly if the clay and shale are several inches or more thick, ground water entering a limestone or dolomite above the clay or shale bed is forced to move laterally through joints and along bedding planes. A ground-water circulation system may thus develop, and when natural erosion or quarrying cuts into the limestone or dolomite, a spring zone may result at or near the top of the clay or shale bed. This is especially true when the limestone or dolomite stratum has a surficial overburden of sand or gravel that is itself water-bearing in the general vicinity of the quarry. Deposits having an overburden of bedrock clay or shale, or of tight surficial clay are less likely to have spring zones.

Spring zones may have associated with them enlarged joints and other underground openings, some of which may have a bearing on quarrying. Such features, even though not now water-bearing, indicate that ground water once was present at the top of a clay or shale bed. Some of the openings may contain clay or silt.

Breccia, Conglomerate, and Nodular Limestones

A number of Illinois limestones contain layers of stone up to 20 feet or more thick that consist of pieces of limestone in a matrix that also is limestone. If the pieces are predominantly angular in shape, the rock is called a breccia (fig. 17); if the pieces are rounded, it is called a conglomerate (fig. 18). The more prominent breccias and conglomerates in Illinois occur in the St. Louis Formation in the western part of the state and in the Wapsipinicon Limestone at Rock Island.

Many Pennsylvanian limestones, especially the Lonsdale and LaSalle Limestones, locally contain comparatively thick beds of limestone whose weathered surface is a closely packed mass of more or less angular fragments or nodules of fine-grained limestone. The fragments are generally less than 2 inches in diameter. Such limestones are called nodular limestones. In unweathered exposures of the limestone its nodular character is not always evident. The lumpy nature of the limestones may be due to the presence of thin shale partings or to zones of weakness between the nodules.

Dolomite Sand

In parts of northwestern Illinois, a red or brown sand consisting of grains of the mineral dolomite has developed to a depth of as much as about 15 feet. The sand apparently was formed by the breakdown of the dolomite rock into its component crystalline particles as a result of weathering. There is generally a gradual downward change at the base of the dolomite sand to easily disaggregated dolomite, which in turn grades into firm dolomite. Some of the sand contains scattered lumps of dolomite rock. There has been a limited use of the sand for agricultural limestone and possibly for other purposes.

Amorphous Limestone and Dolomite

The term "amorphous dolomite" is sometimes applied to a chalky-looking dolomite that displays no visible crystallinity to the naked eye. Samples of amorphous dolomite have been found to consist of very small crystalline particles of the mineral dolomite that have resulted from the partial breakdown of a very fine-grained dolomite rock into its component crystalline particles.

The term "amorphous limestone" may be used for a very fine-grained limestone that has undergone a similar breakdown into its component crystalline particles.

Lithographic limestones are also sometimes called amorphous limestones.

"Whitewash"

"Whitewash" is a term sometimes applied to a white coating that has formed on the surface of weathered deposits of limestone or dolomite. It is usually a thin coating and may be (1) fine quartz particles left behind by the

dissolving of the carbonate materials from the surficial part of an outcrop of siliceous limestone or dolomite, (2) dolomite crystals left as a result of the dissolving of the calcium carbonate from the exposed surface of a dolomitic limestone, or (3) a thin layer of a very fine, partly disaggregated limestone or dolomite akin to the so-called amorphous limestone or dolomite.

Reefs

Under favorable conditions of temperature and water depth in modern oceans, islands known as reefs or atolls are built up. These islands are composed mainly of the hard parts of animals, such as corals, that in their adult life remain attached at one place, and with these are intermingled the remains of shellfish and other kinds of sea animals. The ancient oceans of Illinois also contained reefs and atolls built of the hard parts of corals, shellfish, and similar animals. At times when water temperature and depth were favorable the animals flourished and the reefs enlarged. At other times, there was a smaller animal population and islands of smaller area formed. When a reef built up high enough so that waves were active, debris broken from the reef accumulated in inclined layers along its sides. During reef building other limy sediments were being deposited between the reefs in essentially flat layers. Reefs, reef flank deposits, and interreef strata are shown in figure 32.

There are many reefs in the Silurian rocks of northeastern Illinois. Though originally limestone, they have since been changed to dolomite. Some of them are quite large, extending a mile or more across; some are only a few tens of feet wide. They have been extensively quarried at Thornton and McCook near Chicago and elsewhere in the general area, including Kankakee. Reef dolomite is of high purity and includes some of the most weather-resistant and hard dolomite in northeastern Illinois. In areas where there is only a thin overburden of surficial material, reefs of dolomite in some places make low hills because the surrounding softer rock has been worn away.

Reefs of Silurian age also occur in other parts of Illinois but generally are covered by Pennsylvanian or other rocks. A reef at Grafton and reefs in Whiteside and Rock Island Counties are exceptions. In the central and southwestern parts of the state, ancient buried reefs have served as reservoirs for the accumulation of petroleum that is now being produced from wells drilled into the reefs.

Thickening of Deposits "Back Under the Hill"

The statement is sometimes made that limestone or dolomite deposits, especially thin deposits that crop out in the side of a hill or bluff, "thicken back under the hill." While this is true in some cases, it is not always so. If the limestone or dolomite is exposed in the side of a hill and has a bedrock overburden of shale or sandstone, it is unlikely that it will thicken under the hill simply because it lies beneath a hill. It may naturally thicken in an under-the-hill direction or, conversely, it may thin.

If the limestone or dolomite bed is overlain by surficial materials such as clay, silt, or sand, this indicates that the top of the deposit has been subjected to erosion at some time to remove the bedrock materials that once lay over it. The location of present streams may have little relation to that of the earlier streams and glaciers that wore away the bedrock overburden. Therefore, whether the limestone or dolomite thickens or thins under the hill depends on whether the stone was less or more eroded there than at the outcrop.

The washing and slumping of overburden over outcrops in hillsides or bluffs so that the upper part of the stone stratum is covered is probably a common source of the idea that limestones or dolomites thicken under a hill. In this case the stratum may not actually increase in thickness but it appears to do so because part of it is hidden at the outcrop by overburden. Overburden covering the base of a stone stratum may cause a similar misunderstanding.

Field Characteristics and Relation to Performance

Desirable Properties of Crushed Stone

Soundness and hardness are two properties sought in crushed stone employed for aggregates, railroad ballast, and filter stone that it is often desirable to judge in the field (Lamar, 1961, p. 5-8, 15, 22, 23). In Illinois the sodium sulfate test is used to measure soundness. This test subjects a sample to the disrupting forces of growing crystals and is in this respect similar to actual freezing and thawing of water, although it is probably more severe. Each repetition of the test is called a cycle. Specifications for most uses of crushed stone require that a sample pass five cycles of the soundness test. Filter stone to be used in the filter beds of sewage disposal plants is commonly required to pass 20 cycles of the soundness test with little or no loss.

Hardness is determined in Illinois by the Los Angeles abrasion test, which involves placing a stone sample in a metal cylinder that contains a baffle and steel balls, rotating it a specified number of turns, and determining the amount of breakage sustained by the sample. The weight loss permissible in the Los Angeles test varies with different uses but is generally between 35 and 40 percent.

Major uses for which the soundness and wear tests commonly are specified include base course and surface course stone for crushed stone roads, aggregate for portland cement concrete, bituminous concrete and other bituminous road surfacings, and railroad ballast. Sometimes riprap is required to pass the soundness test.

Field Estimation of Soundness

There is no certain way of predicting in the field whether a limestone or dolomite will pass the soundness test for aggregates unless a backlog of information is available regarding the performance of that particular kind of stone.

However, there are some characteristics that suggest which rocks should be regarded as questionable. In this category are those limestones and dolomites that (1) are comparatively porous and light in weight, (2) have a dull or dusty look when freshly broken and, therefore, are likely to be clayey or silty, (3) contain clay or shale partings, or (4) have, or show signs of developing, a sandy texture. An exception in the matter of porosity is the porous reef dolomite of northeastern Illinois. However, this rock is not light in weight and when it is fresh and gray or white it normally withstands numerous cycles of the soundness test and of freezing and thawing (Willman, 1944) with but little breakage.

Only those Illinois limestones and dolomites that are very dense and nonporous are likely to pass the 20 cycles of the soundness test required for filter stone. Much of the gray or white reef dolomite of northeastern Illinois will pass 20 or more cycles of the test. Rocks that are finely crystalline and do not look dusty may be considered promising. Some oolites and other rocks made up of particles of shells or similar materials in a tight calcite cement, rocks that break cleanly with a smooth surface and a sharp fracture, and those that break with a conchoidal (shell-like) fracture also are worthy of testing.

Field Estimation of Hardness

Estimation during field examination of the probable Los Angeles hardness of limestones and dolomites with no previous performance record is generally impracticable, but some poor-grade materials can be recognized and there are a few helpful clues. Limestones and dolomites whose dry, freshly broken surfaces appear dusty and have a dull appearance are, as has been previously pointed out, likely to contain clay and very small particles of silica, which generally results in a high wear loss. Some dolomites that are yellow or brown will fail the test, as will many limestone or dolomite deposits that have frequent shale partings, are conglomeratic, brecciated, or nodular. Some coarsely crystalline limestones, porous oolitic limestones, or limestones made up of fossil debris that do not have a tight calcite cement may be of marginal hardness. Dolomites that look sandy and clayey limestones and dolomites generally should be regarded with question. Dense, fine-grained limestones, unless they are impure and contain clay, generally have a low wear loss.

Desirable Properties in Building Stone

A primary consideration in judging the quality of building stone for exterior use is its resistance to the destructive effects of the weather. Resistance is considerably influenced by how and where a stone is used in a building. For example, a block of stone that is subjected to frequent thorough wetting by rain or snow water accompanied by freezing and thawing is likely to have a shorter undamaged life than a stone that is not subjected to such conditions, other things being equal.

Color permanence also is a significant characteristic. Many Illinois dolomites are gray when freshly quarried, but after exposure to the weather they turn buff, yellow, or brown. Such color changes commonly are anticipated by those who use such building stone and, therefore, are not regarded as undesirable; in some cases the weathered color is even preferred. Some fine-grained limestones that contain silt or numerous, scattered, small crystals of dolomite develop a whitewashed appearance after long weathering. This happens when some of the surficial calcium carbonate is removed from the exposed surface of the stone and leaves behind a white, chalky residue of the less soluble silt or dolomite particles.

The compressive strength of building stone was once of considerable importance when the walls of buildings carried most of the structural weight. This is of less importance today as the walls of most buildings are not usually load-bearing, except insofar as a stone wall in a house, or similar relatively small structure, may have to bear its own weight.

No generally accepted tests are used to determine the quality of building stones, with the possible exception of tests for water absorption and compressive strength. Low water absorption is often considered desirable, but some limestones with relatively high absorption have given long and satisfactory service as building stones. No generally used minimum values for compressive strength are known to have been specified. However, compressive strength is sometimes determined, apparently because it is assumed that stone having a good strength is likely to be otherwise sound. There may be some basis of fact for such a generalization.

Field Observations for Compressive Strength

No specific means of estimating compressive strength during field examination is known, but, excluding clayey, silty, or cherty rocks, it is probable that the finer grained, dense limestones and dolomites will have the higher strengths. The strength of fresh reef dolomite also is believed to be high, despite the fact that it is porous. Coarsely crystalline limestones usually have intermediate strengths, as do limestones visibly made up of particles in a matrix. Clayey limestones or loosely cemented limestones or dolomites normally have comparatively low strengths. The presence of several percent of quartz sand grains or of small stringers or veinlets of quartz does not appear to reduce the compressive strength of limestones, and the veinlets may even increase it in some cases.

Field Estimation of Weather Resistance

If a limestone or dolomite has not previously been used as a building stone, probably the best means of forecasting its likely performance is to examine outcrops and artificial exposures, such as old roadcuts or railroad cuts, to determine how the stone has withstood the weather. If the stone has spalled noticeably, developed a rough surface, split, or shows other signs of deterioration, it may be expected that the same phenomena will sooner or later appear in the fresh stone, especially that used in the parts of structures

exposed to severe weathering. It is not generally possible to estimate accurately the rate at which these changes will take place in stone in a building or wall or whether or not they will become serious in the course of the ordinary life expectancy of structures of the sort in which the stone is to be used. However, if the approximate date when the artificial exposures were made can be ascertained, it will in some cases give a useful clue to performance. Stone taken from limestone or dolomite deposits that weather into thin layers may not show the layering when freshly quarried, but evidences of it are likely to appear after the stone has been in a wall for a time. Perhaps the best general guide to anticipating the weather resistance of a new building stone is to assume that the stone, when used in a wall, will in time show to some degree the characteristics of weathered outcrops or exposures of the same stone.

As stone was used by the early settlers of Illinois and other parts of the United States as a building material for chimneys, fireplaces, well curbs, foundations, walls, fences, houses, or other structures, the performance of a now unused stone can often be anticipated from an examination of old structures in which it was used. In some cases it may be possible to establish from old records, or by other means, what deposits were the source of the stone. If this is not possible, a study of the texture and, in some cases, the fossils in the stone being considered may show it to be similar to that of the stone in the old structures and thus afford a basis for judging potential performance.

In general, limestones or dolomites having numerous clay partings or containing chert are likely to be of dubious permanence as building stones. Conglomeratic, brecciated, or nodular limestones or dolomites also should be considered questionable unless their weathering characteristics, as shown by exposures or old structures, indicate otherwise.

Texture

Within limits, the texture of Illinois limestones and dolomites has a general bearing on their weather resistance and hence is significant in the evaluation of the building stone possibilities of undeveloped deposits. The limestones of Illinois are of many different textures but for present purposes may be classified, as seen by the naked eye or under low magnification, roughly into five groups: (A) limestones made up principally of fossil fragments in a calcite matrix, (B) oolites—that is, limestones largely composed of oolite grains, (C) fine-grained limestones generally devoid of fossil material, (D) comparatively coarsely crystalline limestones, and (E) medium-grained limestones.

Group A Limestones

The fossiliferous limestones of Group A, in the course of many years of exposure to the weather, often develop a rough surface caused by the wearing

away of the matrix and the small fossil fragments, which leaves the larger pieces of fossils projecting. Stones in the more exposed parts of buildings or those subject to a great deal of wind often weather in this way. In the vertical faces of natural outcrops of Group A limestones, chips or slabs of the stone, often more than a foot wide, may spall off parallel to the exposed rock face. Some deposits that are so situated that gravity does not remove the loosened fossil detritus develop a sand or become so loosely cohesive that they are readily broken down to a sand. However, many limestones of Group A give long and good service as an exterior building stone under normal conditions. They seem less likely to crack under strains that develop in a wall than do the more brittle, fine-grained limestones or dolomites.

Group B Oolites

The oolites of Group B develop a weathered surface somewhat like that of Group A and in many respects weather similarly. Many of them give good service as building stone.

Group C Limestones

The limestones of Group C would generally be regarded as being "harder" than the limestones of Groups A and B because they are fine grained. Many of them are satisfactory building stones. However, usually they are comparatively brittle and chip relatively readily. They commonly have a low porosity, but if even minute cracks are present they can be entered by water, and freezing and thawing may eventually break the stone. Some limestones of Group C, when used in the walls of buildings, seem to have less capacity to adjust to wall stresses than other textural varieties and, therefore, break or split. This may be due to their brittleness. Others may develop a white-washed appearance when they weather, caused by the accumulation of tiny particles of dolomite or quartz at the surface of the stone. These particles are less soluble than the calcite of the stone and have remained after the calcite has been dissolved during weathering.

Group D Limestones

The coarsely crystalline limestones of Group D generally make durable building stones. They may develop a sandy-looking exterior after long weathering. Under suitable conditions they may weather into a sand or to a state in which they can readily be broken down to a sand.

Group E Limestones

The medium-grained limestones of Group E are so diverse that no general weathering characteristics can be set up for them, but they tend to weather like whichever rock of the preceding groups they most closely resemble.

Dolomite

Illinois dolomites range from very fine grained to comparatively coarse grained. They vary in porosity. Reef dolomite is quite porous and some of it, when sawed, resembles travertine. Although the dolomites contain some fossils, the fossils are generally not as abundant as they are in some limestones. Many, perhaps most, of the dolomites of Illinois are made up of grains that within any given sample are likely to be of about the same size or lie within a comparatively limited size range. On very long exposure to the weather the crystalline particles may break apart. When this happens the coarse-grained dolomites become sand and the very finely crystalline dolomites become chalky. This characteristic is responsible for the sanding off, or powdering off, of dolomites in exposed positions in some older structures. Many different dolomites have given good service in Illinois as building stone.

Relation of Field Characteristics to Chemical Composition

Nomenclature

From the standpoint of the use of limestones and dolomites, their chemical composition is of major importance. A number of terms, such as "high-calcium limestone," "high-purity limestone," "high-magnesium dolomite," and "high-purity dolomite" have developed and are used industrially with reasonably consistent meanings. The term "high-calcium limestone" is applied to limestones containing more than 95 percent calcium carbonate, but many, if not most, commercial high-calcium limestones are believed to contain more than 97 or 98 percent calcium carbonate. Such limestones are in some cases called high-purity limestones.

Dolomites containing more than 42 percent magnesium carbonate or 20 percent magnesium oxide are called high-magnesium dolomites. The term "high-purity dolomite" has been used (Willman, 1943, p. 13) to describe dolomites containing more than 42 percent magnesium carbonate and more than 97 percent magnesium carbonate and calcium carbonate together. In its form for reporting the production of limestone and dolomite, the U. S. Bureau of Mines (1960) uses the following categories: high calcium—95% + $CaCO_3$; low magnesium—5 to 25 percent $MgCO_3$; and high magnesium or dolomite—25 to 45 percent $MgCO_3$.

Field Tests for Distinguishing Limestone and Dolomite

The recognition in the field of the various chemical grades of limestone and dolomite mentioned is not an easy matter and depends to a considerable degree upon the observer's experience with limestones and dolomites whose chemical composition are known. A primary determination is whether a stone is limestone or dolomite. In Illinois, calcareous rocks that are brown or yellow are likely to be dolomite or dolomitic. However, many dolomites are

almost white or gray when freshly exposed and become yellow or brown only when weathered. Conversely, many calcareous rocks that are white and those of various shades of gray, black, or almost black are likely to be limestones. A few weathered exposures of such rocks are yellow or light brown. The reef rock dolomite in northeastern Illinois is an exception to the foregoing as it is gray when freshly exposed and becomes yellow or brown only after it has been exposed to the weather for a long time.

Some dolomites, especially those cropping out in northwestern Illinois, contain holes, most less than an inch in diameter, many of which are partly filled with sand consisting of grains of dolomite. Locally the rock has completely broken down into a sand. This phenomenon is uncommon in limestones.

Dilute hydrochloric acid may be used to distinguish between limestone and dolomite. When the acid is applied to a freshly broken, dust-free surface of a piece of carbonate rock, vigorous effervescence results if the rock is limestone, whereas only slight and possibly tardy effervescence results if the rock is dolomite. If this test is used out-of-doors in cold weather, the reaction on a piece of dolomite may be so slow that effervescence, if any, is hardly noticeable.

Staining tests, discussed subsequently, also are useful in identifying limestone and dolomite in the field.

Field Tests for Calcareous Sandstone

Calcareous sandstone, also known as bastard sandstone, resembles some limestones in appearance and is often mistaken for limestone. This is particularly true of some calcareous sandstones of Pennsylvanian age. The sandstones are commonly gray, dark gray, or brown, hard, nonporous, and firmly cemented by calcite. They effervesce with hydrochloric acid, as do limestones, which is one of the reasons they are mistaken for limestone. However, normal limestones will not scratch glass but the sandstones do because the sand grains composing them are dominantly the hard mineral quartz.

Freshly broken surfaces of some hand samples of calcareous sandstone glisten or shine when held in the proper position in the sun or strong light. This is believed to be due to the fact that the calcite within each shiny area is part of a single calcite crystal that extends through many pores as the cementing material.

Tests on a sizable number of samples suggest that the carbonate content or calcium carbonate equivalent of the sandstones rarely exceeds 30 percent. It is believed the rock would be abrasive to crushing equipment. No commercial production of calcareous sandstone is known to have occurred in the state.

Field Estimates of Purity and Composition

Estimates of the purity of limestones and dolomites depend in a large measure on the recognition of impurities. A limestone or dolomite containing

TABLE 7—PHOSPHORUS PENTOXIDE, MANGANESE OXIDE, AND SULFUR TRIOXIDE IN ILLINOIS LIMESTONES AND DOLOMITES CONTAINING MORE THAN 95 PERCENT CARBONATES*

	No. of samples	Average (%)	Range (%)
Phosphorus Pentoxide (P_2O_5)			
Limestone	26	.039	.004 – .097
Dolomite	16	.006	.000 – .032
Manganese Oxide (MnO)			
Limestone	12	.015	.002 – .044
Dolomite	14	.040	.010 – .050
Sulfur Trioxide (SO_3)			
Limestone	29	.13	.00 – .88
Dolomite	39	.17	.02 – .59

* Lamar (1957).

numerous chert nodules or beds, clay partings, or sand grains visible to the naked eye or with a magnifying lens obviously is likely to be impure. Examination of weathered outcrops will sometimes reveal the presence of clay or sand that may not be evident in the fresh stone. If the rocks are tested with hydrochloric acid and the resulting froth breaks down to a dirty scum, impurities are present.

Limestones or dolomites that have a dull, dusty appearance may be impure. Many chert-free limestones and dolomites occurring in thick beds are comparatively pure, whereas some thin-bedded varieties are only moderately pure or are impure. Coarsely crystalline limestones and dolomites frequently are of high purity, as are some of these rocks that are very fine grained (lithographic limestones). Limestones or dolomites that are parts of deposits containing abundant shale or clay partings or sandstone beds may themselves be clayey or sandy.

If stone of low silica content is being sought, the presence of chert, quartz veinlets, sand, or silt is detrimental because they are major sources of silica. Low-alumina stone should not contain clay or shale, as clay and shale are a principal source of alumina in carbonate rocks.

Iron oxide, iron sulfide, and organic material are other impurities in limestones and dolomites. The first may be present as the yellow, brown, or red hydrated iron oxides, and a very small amount of these oxides can produce a readily noticeable color. Pyrite and marcasite, which consist of iron sulfide, obviously are undesirable in a stone required to have a low sulfur or sulfur trioxide content. Organic material in Illinois carbonate rocks is commonly black or dark gray and is likely to be more abundant in rocks of these colors than in white or light colored limestones and dolomites.

Other substances that are significant to certain uses of high-calcium limestone and high-magnesium dolomite and hence are reported in some chemical analyses are phosphorus (P) or phosphorus pentoxide (P_2O_5), and manganese oxide (MnO). The presence of phosphatic nodules in limestones or dolomites suggests a higher than normal phosphorus content. A few thin

limestones of Pennsylvanian age in Illinois contain scattered nodules of this sort. No other means are known for forecasting phosphorus content in Illinois limestones and dolomites during field examination. Summary data on the phosphorus pentoxide content of limestones and dolomites are given in table 7 that suggest limestones are likely to contain more phosphorus pentoxide than dolomites.

Similar data on manganese oxide suggest that dolomites may contain more of the oxide than limestones. No means is known for estimating manganese oxide content in the field in the amounts shown in table 7. Studies of the manganese content in samples of Illinois Pennsylvanian limestones showed a range of 0.04 to 0.37 percent Mn and an average of 0.14 percent Mn (Ostrom, 1957, p. 29). These values would be equivalent to 0.05 to 0.47 percent MnO and an average of 0.18 percent. The determinations of manganese content were made by means of a spectrograph, whereas the manganese data mentioned earlier were obtained by wet gravimetric chemical analyses. These data for the Pennsylvanian limestones are higher than those for Illinois limestones generally (table 7), but the difference may result, at least in part, because the same method of analysis was not used in both cases.

The data on sulfur trioxide in table 7 are about the same for both limestone and dolomite. The presence of pyrite or marcasite in either type of stone will increase the sulfur or sulfur trioxide content as these minerals are more than one-half sulfur. Gypsum ($CaSO_4 \cdot 2H_2O$) and anhydrite ($CaSO_4$) also contain sulfur but are rarely found in outcropping limestones and dolomites in Illinois, although they have been found in diamond drill cores at depths of 600 feet or more.

Laboratory Tests on Limestones and Dolomites

A variety of tests are made on limestones and dolomites to determine their chemical or physical properties. Some of the more important of these that relate to Illinois rocks and their uses are discussed below. The descriptions give a general idea, rather than a detailed account, of how the tests are made and of what they indicate.

Some of the tests have a bearing on the uses of limestone and dolomite. Other tests, relating to texture and mineral composition, are included that may be useful to quarrymen or may be referred to in reports or articles.

Examination for Approximate Composition and Texture

Insoluble Residue Test

In the insoluble residue test, a sample of limestone or dolomite is ground, weighed, and treated with hydrochloric acid, which dissolves the minerals calcite and dolomite in the rock. Other acids may be used instead of hydrochloric acid. Heating usually is needed to speed up the solution of the dolo-

mite. The impurities in the sample, such as quartz grains, chert, pyrite, and most of the clay do not dissolve. The residue of impurities is collected on a filter paper, or recovered by other means, and weighed. The percentage of impurities in the sample can be determined by dividing the weight of the residue by the weight of the original sample. Because some kinds of clay may be more or less dissolved during the acid treatment, the results of tests on clayey limestones or dolomites may be somewhat inaccurate. The presence of other acid-soluble minerals, such as siderite, in the samples also affects the results. Insoluble residue tests are, nevertheless, a rapid means of obtaining a reasonably good idea of the amount of carbonates and impurities in a limestone or dolomite. Examination of the residue with a microscope gives information regarding the nature of the impurities in the sample and is helpful in determining the amount, particle size, and particle shape of any quartz grains present. These are some of the materials that are sometimes referred to as free quartz or free silica.

Etching Test

In the etching test, a piece of limestone or dolomite with a smoothed surface is immersed in dilute hydrochloric, acetic, or some other acid, with its

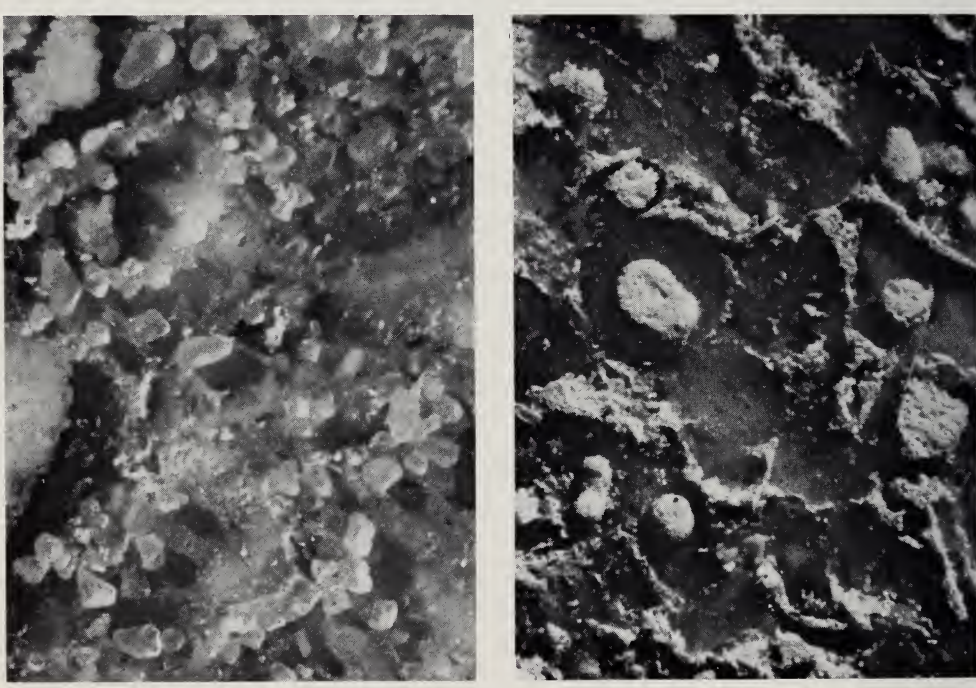

FIG. 43—Photographs of two limestone specimens that have been etched with hydrochloric acid. A sandy limestone is shown on the left; after etching, the sand grains project above the etched surface and are clearly recognizable. The specimen on the right shows masses of fine-grained silica projecting above the calcite part of the limestone. Enlarged about 20 times.

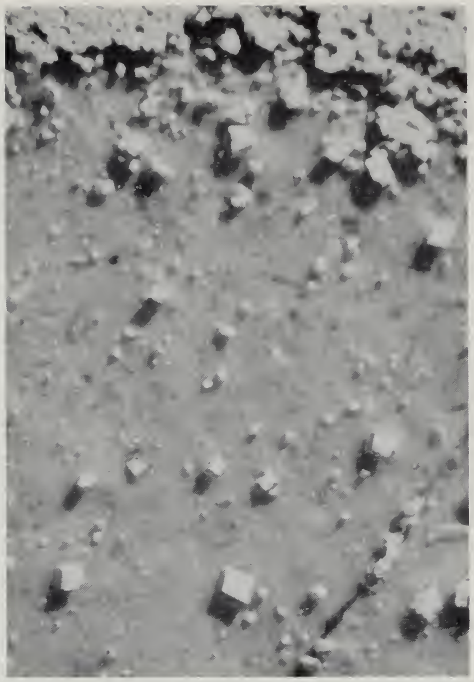

FIG. 44—Specimen of dolomitic limestone etched by hydrochloric acid. The scattered little blocks, or rhombs, that project above the groundmass of the sample are the mineral dolomite. An abundance of dolomite grains occurs at the top margin of the photograph. The material that has been dissolved from the sample is calcite. Enlarged about 20 times.

smoothed surface parallel to the surface of the acid bath. During the immersion some of the carbonates of the sample are dissolved (fig. 43) leaving the impurities behind (Lamar, 1950). If dilute acid is used and the period of etching is short, the dolomite crystals in dolomitic limestones are left protruding above the etched surface (fig. 44).

Examination of a smoothed surface with a microscope after etching reveals the distribution of impurities and their character. The test is helpful in revealing the presence of banded ingredients that may constitute planes of weakness, such as clay seams. Hydrochloric acid is generally preferable to acetic acid for revealing impurities, but the acetic acid reveals more of the textural details of a sample, the differences in the rate of solution of the carbonate components, and the presence of small cracks or joints. For many limestones, acetic acid etching gives an idea of the kind of surface that will develop after long exposure to the weather. The results of etching tests are usually more striking with limestones than with dolomites.

Smoothed and Polished Surfaces

Polishing brings out the texture of many limestones and dolomites and facilitates microscopic examination. Wetting surfaces that have been smoothed by means of a fine abrasive with water or oil or spraying them with clear plastic also aids in the study of texture.

FIG. 45—Photograph of thin section of limestone from near Prairie du Rocher. It consists of pieces of fossils in a matrix of crystalline calcite. The fossil fragments also are made of crystalline particles, as is evident by the crystalline mosaic in some of them. An oolite grain occurs near the center of the top margin. Salem Limestone. Enlarged 20 times.

Thin Sections

A thin section of a rock is made by cementing a small slice of the rock to a piece of glass and then grinding away the rock slice until such a thin portion remains that it will permit the ready passage of light. A desirable thickness for the rock slice is 0.03 mm (Reed and Mergner, 1953). A very thin cover glass is cemented over the rock slice to protect it. Figures 15, 16, and 45 are photographs of limestone and dolomite thin sections made through a microscope. When a thin section is examined under the petrographic microscope it is possible to see the size, arrangement, and character of the crystalline particles composing a rock and to identify its mineral constituents. This technique is commonly used in detailed studies of limestones and dolomites.

Peels

Peels of limestone or dolomite are generally made by applying to a smoothed, slightly etched surface of rock a liquid that subsequently hardens to a pliable film (Bissell, 1957) or by applying commercial cellulose acetate film on the smoothed etched surface and wetting it with acetone. The film is thus softened so that it conforms to the etched surface (McCone, 1963). In both methods the film is pulled away when it has hardened and reveals the textural details of the stone (fig. 46).

Staining Tests

A number of staining methods are available for the identification of the carbonate minerals in limestone and dolomite. These were described by Friedman (1959). They are generally used in the laboratory but may also be employed outdoors although those involving dilute hydrochloric acid may be ineffective or slow in cold weather because the acid reacts slowly under such conditions.

One staining test for dolomite involves dilute hydrochloric acid in which a small amount of potassium ferricyanide has been dissolved, producing a yellow solution. When this solution is applied to dolomite the ferricyanide reacts with the ferrous iron present in many dolomites and produces a dark blue, stain-like deposit. As limestone usually does not contain ferrous iron, it generally is not colored by the ferricyanide. However, the test is specifically for ferrous iron and not for dolomite and should be so interpreted. Potassium ferricyanide is poisonous and should be handled with care.

In another staining test for the mineral dolomite a solution of 0.2 grams of the dye alizarin red is used in 25 cc of methanol to which 15 cc of a 30 percent solution of caustic soda (NaOH) are added. This solution turns dolomite a reddish purple in a few minutes (Friedman, 1959).

The calcite in limestones may be selectively stained by immersing the stone in a dilute ferric chloride solution and then in an ammonium sulfide solution saturated by hydrogen sulfide. Calcite is stained black. Another

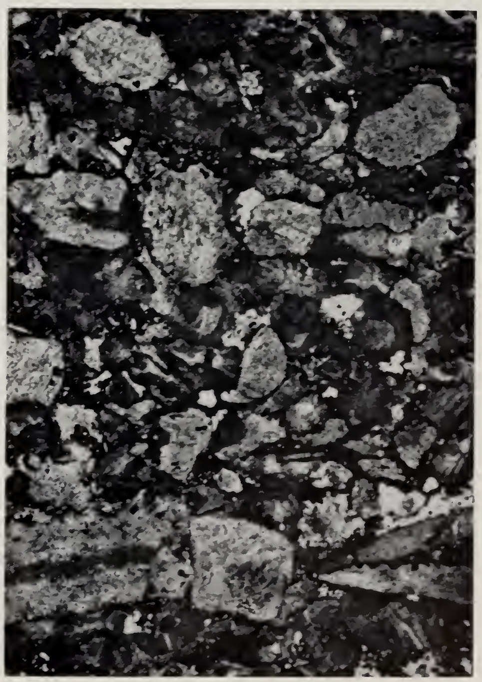

FIG. 46—Photograph of an acetate peel made from a sample of limestone. Transmitted light. The large pieces of material shown are thought to be mostly fragments of crinoid stems. Many of the finer particles are fragments of bryozoa. Salem Limestone. Magnified about 16 times.

test (Friedman, 1959) employs a solution of 0.1 gram alizarin red in 100 cc of 0.2 percent cold hydrochloric acid. Calcite is stained deep red in a few minutes.

Staining tests can be applied to any type of limestone or dolomite surface but are easiest to interpret on a smoothed, polished, or acid-etched surface. They are often useful in identifying the grains that project from etched surfaces, such as the dolomite grains in figure 44.

Wet Chemical Tests for Composition

A variety of chemical tests are made on limestones and dolomites to determine their chemical composition and hence their value for various uses. Those described are believed to be the more commonly made.

Wet Gravimetric Analysis

By suitable procedures the analytical chemist can determine the amount, in percent by weight, of a great many substances in limestones and dolomites (Hillebrand and Lundell, 1953). When the expression "chemical analysis" is used without other descriptive terms, wet gravimetric analysis is usually meant. Most chemical analyses of limestones and dolomites report calcium oxide (CaO), magnesium oxide (MgO), alumina (Al_2O_3), silica (SiO_2), iron oxide (Fe_2O_3), and either loss on ignition or the amount of carbon dioxide (CO_2) present. Sodium oxide (Na_2O) and potassium oxide (K_2O) also are often reported, and manganese oxide (MnO), phosphorus (P) or phosphorus pentoxide (P_2O_5), and sulfur (S) or sulfur trioxide (SO_3) are determined if they are pertinent to the intended use of the stone.

The first step in making a wet gravimetric analysis involves getting the sample into solution. Thereafter, determinations of the various compounds are usually made chiefly by producing precipitates of them.

The oxides reported in the analyses for the most part do not occur as such in the sample. In chemical analyses of Illinois limestones and dolomites the most commonly reported oxides and their principal manners of occurrence are as follows:

Calcium oxide	Part of the mineral calcite or the mineral dolomite
Magnesium oxide	Part of the mineral dolomite; possibly part of clay mineral material
Aluminum oxide (alumina)	Part of the clay mineral material
Silicon dioxide (silica)	Quartz silt, sand grains, chert, or part of clay mineral material
Iron oxide	Iron oxide or the hydrated iron oxide; a component of pyrite or marcasite; part of the clay mineral material
Sodium and potassium oxides	Part of the clay mineral material; possibly in the liquid of fluid inclusions
Carbon dioxide	Part of the minerals calcite and dolomite

The standard wet gravimetric analysis does not give a measure of the free silica or free quartz in a sample unless the clay content of the sample is insignificant.

The specifications for many uses of limestone and dolomite give limits for calcium carbonate ($CaCO_3$) or magnesium carbonate ($MgCO_3$) rather than for calcium oxide (CaO) and magnesium oxide (MgO). The percentage of calcium carbonate may be calculated from the percentage of calcium oxide by multiplying the latter by 1.785. To convert magnesium oxide data to magnesium carbonate data, 2.091 is used as the multiplier.

Versenate or EDTA Analysis

A rapid test for calcium and magnesium oxides is made by means of versenate reagent or EDTA (ethylenediaminetetracetic acid) (Hildebrand and Reilley, 1957; Schmid and Reilley, 1957; Bisque, 1961; Diebold, Lemish, and Hiltrop, 1963). The procedure does not involve fusion of samples; instead, only that part of the sample that is acid soluble is analyzed and the quantities of various components are determined by titration. The acid-soluble material includes the calcite and dolomite present and, to a lesser extent, some other minerals. Versenate analyses probably are not as accurate as wet gravimetric analyses, but they serve a useful purpose when speed is important.

Calcium Carbonate Equivalent

The calcium carbonate equivalent test (Assoc. Off. Agr. Chem., 1955) is made to determine the capacity of limestones and dolomites to neutralize acids. The weight of acid required to react with all the calcium carbonate and calcium magnesium carbonate in a 1-gram sample of the stone being tested is determined. The weight of calcium carbonate needed to neutralize this weight of acid is calculated. This figure divided by the weight of the sample gives, in percent, the calcium carbonate equivalent, often abbreviated as C.C.E. Pure calcite limestone has an equivalent of 100 percent; that of pure dolomites is almost 109 percent, a figure possible because a given weight of magnesium carbonate neutralizes about one-fifth more acid than does the same weight of calcium carbonate.

Instrumental Chemical Analysis

Several procedures are used for analyzing limestones and dolomites by means of instruments that measure changes produced in certain kinds of radiation when rays are passed through or impinged upon rock samples. X-rays and infrared radiation are such means of analysis. X-ray diffraction is particularly useful for determining mineralogical composition, from which approximate chemical composition may be deduced. Infrared radia-

tion is of value in identifying the presence of certain special compounds, such as opaline silica.

Analytical procedures involving examination of light spectra include flame photometry, emission spectrography, and X-ray fluorescence. In general, the kinds of radiation given off when a rock sample is burned or placed in an X-ray beam are used to identify the elements present; the amount of each type of radiation emitted is proportional to the concentration.

Flame photometry utilizes the spectrum produced when a sample is burned in a flame and is used for determining sodium, potassium, and lithium. Emission spectrography involves analysis of the spectrum resulting from burning a sample in an electric arc or spark and is employed to determine a large number of elements; it is especially useful in analyzing very small quantities of material. In X-ray fluorescence, rock and mineral samples are placed in a beam of X-rays and caused to fluoresce. The resulting X-ray spectrum is examined to determine the kind and amount of the various chemical elements present. Chemical analyses having an accuracy approaching wet gravimetric analyses can be made by this method.

Calculations from Chemical Analyses

A number of calculations relating to mineral composition can be made from a detailed chemical analysis of a limestone or dolomite. Of common interest to the quarryman, however, are data on the amounts of calcium carbonate ($CaCO_3$), magnesium carbonate ($MgCO_3$), dolomite ($CaCO_3 \cdot MgCO_3$), free silica, and the calcium carbonate equivalent.

Calculation of $CaCO_3$ and $MgCO_3$

A common way of calculating the amount of calcium carbonate or magnesium carbonate in a limestone or dolomite is to multiply the percentage of calcium oxide or magnesium oxide reported in the chemical analysis by suitable factors, as follows:

$$\%\ CaO \times 1.785 = \%\ CaCO_3$$
$$\%\ MgO \times 2.091 = \%\ MgCO_3$$

The difference between the percentage of calcium oxide and the percentage of calcium carbonate is the percentage of carbon dioxide involved in changing the oxide to the carbonate. The same applies to the difference between the magnesium oxide and the magnesium carbonate.

The percentage of calcium carbonate plus the percentage of magnesium carbonate calculated as above is in some cases greater than the sum of the percentages of calcium oxide, magnesium oxide, and carbon dioxide reported in the chemical analysis of the sample. The difference may result because of the presence of compounds such as gypsum ($CaSO_4 \cdot 2H_2O$), anhydrite ($CaSO_4$), and certain magnesium-bearing clay minerals that contain calcium

or magnesium in compounds other than calcium carbonate or magnesium carbonate. The calcium and magnesium contained by these minerals is reported as calcium oxide and magnesium oxide in the chemical analysis and is not distinguished from the calcium oxide and magnesium oxide that come from the calcium carbonate and magnesium carbonate in the original sample. Therefore, calculations of calcium carbonate and magnesium carbonate as described above may be somewhat too high for some rocks.

A procedure sometimes followed to avoid the foregoing possible error assumes that there is more likely to be noncarbonate magnesium occurring in clay in the ordinary limestone or dolomite than noncarbonate calcium. The steps involved are:

1. Calculate CaO to $CaCO_3$ (% $CaO \times 1.785$).
2. Determine the amount of CO_2 so used (% $CaCO_3$ − % CaO).
3. Determine remaining amount of CO_2 (% CO_2 given in the chemical analysis minus the % CO_2 in step 2).
4. Determine the amount of $MgCO_3$ that can be formed from the amount of CO_2 remaining, step 3 (CO_2 remaining $\times$ 1.916).

Often such a calculation does not use all the magnesium oxide reported in the chemical analysis; it is then considered to occur in some form other than magnesium carbonate. The difference between the total calcium carbonate and magnesium carbonate calculated as above and that arrived at by direct multiplication of the amount of oxides by factors is generally quite small for pure limestones and dolomites but may be several percentage points for impure limestones or dolomites, especially those whose aluminum oxide content indicates they contain considerable clay.

Calculation of Amount of Dolomite

The simplest way to obtain from a chemical analysis an approximate figure on the amount of dolomite mineral in a sample is to multiply the percentage of magnesium oxide by 4.574. However, the resulting figure may be between 0.5 and 2 percent too low for some Illinois dolomitic rocks, especially when the amount of magnesium oxide exceeds about 18 percent. If it does exceed this figure, the dolomite mineral content is probably better approximated by adding the percentages of calcium carbonate and magnesium carbonate.

Calculation of Free Silica

The amount of free silica in a limestone or dolomite is normally equal to the percentage of silica reported in the chemical analysis if the percentage of alumina reported is low. If the amount of alumina is more than 2 percent, however, an appreciable amount of clay is probably present in the stone. As some common clay minerals found in limestones and dolomites

may contain as much as 2 percent silica (W. A. White, personal communication, 1967) for each 1 percent of alumina, the amount of free silica is thus reduced by the amount of silica tied up in the clay. For each 1 percent of alumina, 2 percent silica may be subtracted from the amount of silica reported in the chemical analysis to obtain an approximation of the amount of free silica in clayey limestones or dolomites, but the resulting figure is a probable minimum for the amount of free silica actually present.

Calcium Carbonate Equivalent

As the calcium carbonate equivalent measures ability to neutralize acid and a given weight of magnesium carbonate is 1.19 times as effective as the same weight of calcium carbonate in this respect, the calcium carbonate equivalent of a limestone or dolomite may usually be closely approximated from a chemical analysis as follows:

$$\%\ CaCO_3 + (1.19 \times \%\ MgCO_3) = \text{calcium carbonate equivalent.}$$

Tests Involving Heating

Decrepitation Test

Sand-sized particles of some limestones and dolomites break apart, or decrepitate, when heated, probably because they contain tiny inclusions of water. The water is converted to steam during heating and the escape of the steam ruptures the grains with some violence. Tests on Illinois limestones and dolomites indicate that most of the decrepitation occurs between 325° and 425° C (617° to 752° F) (Lamar and Shrode, 1953, p. 109). A decrepitation test is made for limestones and dolomites to be used in glass making and possibly for other uses.

Differential Thermal Analysis

The procedures for a differential thermal analysis test vary somewhat, but a common one involves, in outline, placing a sample of finely powdered limestone or dolomite in a small cavity in a small block of a heat-resistant metal and inserting a thermocouple into the powder to measure temperature. A similar metal block is filled with alumina powder and a thermocouple inserted in it. Both blocks with their thermocouples are placed in an electric furnace that is heated at a constant rate to at least 1000° C (1832° F). The alumina undergoes no change during heating and the thermocouple in it registers the temperature of the furnace. However, limestone and dolomite give off carbon dioxide during heating, and when this happens their temperature lags behind that of the furnace. The difference between the temperature of the furnace and that of the limestone or dolomite sample is traced by a re-

cording instrument as a line or "curve" on a chart. The calcite that composes limestone gives off its carbon dioxide between 840° and 990° C (Graf and Lamar, 1955, p. 693) and this phenomenon is recorded as a "V" or "peak" on the curve. The mineral dolomite that composes the rock dolomite gives off its carbon dioxide at 810° ± 15° C and at 940° ± 25° C, and hence the curve for dolomite has two V-shaped peaks. The foregoing temperatures may vary somewhat according to the particle size of the limestone and dolomite powders and other factors (Graf and Lamar, 1955).

Differential thermal analyses are useful for studying the lime-making properties of limestones and dolomites and also are employed in investigating the reactions that occur in the burning of portland cement mixes.

Tests of Physical Properties

Thermal Expansion

As applied to limestone and dolomite, thermal expansion refers to their expansion when heated. The amount of expansion is determined by very exact measurements of the change in length of test bars while they are being subjected to temperature changes, commonly from 0° to 212° F, 32° to 212° F, or some similar range. The expansion is expressed as a coefficient of expansion. This indicates the average expansion in length of a bar of limestone or dolomite of a particular unit of length, such as 1 inch, when its temperature is raised 1° F within the temperature range of the tests on which the coefficient is based. For example, the expansion in inches of a 20-foot bar of dolomite, having a coefficient of expansion of 0.0000045, if the temperature changed from 50° to 100° F, would be calculated as follows: Length of bar in inches (240) × temperature change (50° F) × coefficient of expansion of the dolomite (0.0000045) = 0.054 inches.

Sixteen samples of relatively pure Illinois limestones had coefficients of thermal expansion ranging from 0.0000019 to 0.0000039 per degree Fahrenheit and averaged 0.0000022 in the range −4° to 140° F (Harvey, 1966, p. 1, 4). The fine-grained limestones expanded at a nearly constant rate, but the coarse-grained limestones expanded more rapidly as the temperature increased. In the same temperature range, 18 samples of Illinois dolomite had coefficients of thermal expansion ranging from 0.0000040 to 0.0000055 and averaging 0.0000046 (R. D. Harvey, personal communication, 1966). In the range from room temperature to 212° F, Griffin (1936, p. 27) found that 16 samples of various kinds of limestones had coefficients of expansion between 0.0000017 and 0.0000068 per degree Fahrenheit; two dolomites had coefficients of 0.0000058 per degree Fahrenheit.

Hardness Tests

The term "hardness" as applied to limestone and dolomite may be used in many different ways; it can mean their resistance to a blow (impact and toughness tests), to abrasion (Dorry, Los Angeles, and Deval wear tests),

to scratching (Mohs hardness test), to compression (compressive strength test), to bending (transverse strength test) and to tension (tensile strength test).

Compressive, Transverse, and Tensile Strength Tests

The tests for compressive, transverse, and tensile strength have been or are made on building stones; it is believed that compressive strength is the test most commonly made at the present time. It is measured by determining the pressure in pounds per square inch necessary to break a 2-inch cube of limestone or dolomite or a cylinder of the stone 2 inches in diameter and 2 inches high. The transverse strength, expressed as the modulus of rupture, is determined as the pressure in pounds per square inch necessary to break a bar of stone. The tensile strength is the force in pounds per square inch required to pull apart a test specimen. Methods of testing are closely specified (ASTM, 1961b, p. 758–763).

Compressive strength tests (Woolf, 1953, 33–36; Shaw, 1873, p. 157) of Illinois rocks indicate a range of from 8,650 to 25,850 pounds per square inch for dolomite and 8,580 to 35,320 pounds per square inch for limestone. Unpublished data suggest that some samples of both rocks may have a lower minimum value than those stated.

Toughness Test

The toughness test has been used for testing limestone and dolomite for aggregates. The test involves dropping a 1-kilogram plunger having a spherical end against one end of a cylinder of stone 25 mm (about 1 inch) in diameter and 25 mm high. The plunger is allowed to strike the cylinder from an initial height of 1 centimeter (cm) and the height of fall is increased by 1 cm each time the plunger falls. The height of the fall of the plunger in centimeters when the rock cylinder breaks is called the toughness (ASTM, 1961a, p. 613). Toughness tests of over 190 samples of Illinois limestones and dolomites showed a range of from 3 to 20 (Krey and Lamar, 1925, p. 47–62).

Impact Resistance Test

The impact resistance test described by Harvey (1963), in which a ⅜-inch steel plunger having a 5/32-inch hardened steel sphere at its lower end is dropped 6 cm to strike a smooth-surfaced block of limestone or dolomite, is another hardness test. Five indentations are made at different places on each test specimen and the size of the indentations are measured under a microscope and averaged. Results are expressed in terms of an impact modulus; the nature and amount of disturbance produced in the rock surrounding the indentation also is significant.

The impact modulus of 26 pure Illinois limestones ranged from 77 to 275 and averaged 196, and for 10 pure Illinois dolomites was from 149 to 422,

averaging 336. The larger the modulus, the smaller were the indentations produced and hence the harder the rock. The average impact modulus for the fine-grained limestones tested was greater than that for the medium-grained samples, whose average modulus was, in turn, higher than that of the coarse-grained samples. The same relations existed for the dolomites.

Mohs Hardness Test

A test sometimes used to obtain information about the hardness of limestone or dolomite or of their mineral impurities is the Mohs hardness test, which is a type of scratch test. It involves the use of a scale based on minerals of various degrees of hardness.

MOHS HARDNESS SCALE

1. Talc	6. Orthoclase
2. Gypsum	7. Quartz
3. Calcite	8. Topaz
4. Fluorite	9. Corundum
5. Apatite	10. Diamond

The hardness of a substance is found by determining which of the minerals in the scale it will and will not scratch. For example, if a substance will scratch fluorite but not apatite, its hardness is between 4 and 5, or about 4.5. The approximate hardness of some commonly available articles is 2 for a fingernail, about 3 for a cent, a little above 5 for an ordinary pocket knife, and above 5.5 for ordinary window glass. The hardness of pure limestone is 3 and of pure dolomite from 3.5 to 4. Impurities may affect hardness. Quartz, in particular, with its hardness of 7, can affect the scratch hardness of limestone and dolomite when it occurs in them as finely disseminated particles, sand grains, or chert.

Dorry Hardness Test

Another hardness test involves the use of the Dorry hardness machine. A cylinder 4 inches long and 1 inch in diameter, with carefully squared ends, is made from the stone to be tested. This is weighed and then held vertically in a clamp against a horizontal rotating metal plate to which sand is fed at a constant rate. The cylinder starts the test under a specified load. After 1000 revolutions of the rotating plate the weight loss suffered by the rock cylinder is determined. The other end of the cylinder is then tested. A hardness coefficient is calculated by dividing the average weight loss of the cylinder by 3 and subtracting the results from 20 (Barton and Doane, 1925, p. 151–153; Woolf, 1953, p. 3). This test was made when steel-tired vehicles were in common use on roads and is not known to be employed at present in Illinois for the testing of aggregates. However, Dorry hardness tests made earlier on the 155 samples of Illinois limestones and dolomites (Krey and Lamar, 1925, p. 47–62) show a range in hardness coefficient of from 8.7 to 19.4 for limestones and from 7.5 to 18.5 for dolomites.

Los Angeles Abrasion Test

The Los Angeles abrasion test (ASTM, 1961a, p. 534–536) is used in Illinois and other states to determine the resistance to abrasion of coarse aggregates that are to be used in roads and concrete (Ill. Divn. Highways, 1958, p. 610–619). The test involves the use of the Los Angeles machine, which is a cylindrical drum in which a baffle extends from the side of the cylinder. A sample of stone to be tested, graded to certain specified sieve sizes and of stated weight, is placed in the cylinder with a specified number (not more than 12) of steel balls that are slightly less than 2 inches in diameter. The cylinder is rotated 500 or 1000 revolutions, depending on the particle size of the sample and the number of balls used. The sample is then sieved on a no. 12 sieve and the amount retained determined by weight; the amount of material passing the no. 12 sieve is determined by difference. Its weight is divided by the weight of the original sample to give the percentage of loss, or percentage of wear. In the test, the particles of the sample abrade each other, are abraded by and crushed between the steel balls, and also are broken by the impact resulting when the steel balls fall from the baffle as the cylinder rotates.

Many Illinois limestones and dolomites pass the Los Angeles test for aggregates. However, limestones that do not pass are likely to be clayey, shaly, or silty and usually comparatively light in weight. Some coarsely crystalline limestones, impure dolomites, and dolomites that are sandy also may fail the test. Unsuitable dolomites often are light in weight and have a high water absorption.

Deval Abrasion Test

Another abrasion test applied to limestone and dolomite aggregates involves the use of the Deval abrasion machine (ASTM, 1961a, p. 537–539). This machine consists of a cast iron cylinder a little less than 13½ inches long that is affixed to a shaft at an angle of 30 degrees to its axis of rotation. A sample of crushed stone of specified particle size and weight, depending on the specific gravity of the stone, is placed in the cylinder with 6 steel balls roughly 1⅞ inches in diameter. The cylinder is closed and rotated 10,000 revolutions. The percentage of wear is calculated as in the Los Angeles test. A value known as the "French coefficient of wear" can be calculated from the percentage of wear by dividing 40 by it.

Tests made some years ago on more than 200 Illinois limestones and dolomites (Krey and Lamar, 1925, p. 47–62) show percentage of wear values ranging from 2.8 to 9.7 for limestones and 2.5 to 16.0 for dolomites, but the average values of the two rocks are essentially the same.

Abrasiveness of Carbonate Rocks

The abrasion tests previously mentioned relate to the resistance of limestones and dolomites to abrasion. Another aspect of abrasion that is im-

portant in some circumstances, especially in the consideration of new deposits, is the abrasiveness of limestones or dolomites to crushing and pulverizing equipment. The most common abrasive substance in calcareous rocks is quartz, which occurs principally, as has been previously indicated, as chert, sand, or silt. No standard tests are known for abrasiveness of the type under discussion, but 5 percent is sometimes given as the maximum amount of free quartz or free silica allowable. Free silica content and the size of the silica particles can be estimated from a study of insoluble residues under the microscope. Calculations from chemical analyses in some cases also provide an estimate of the amount of free silica. Microscopic examination of etched specimens and thin sections are other means of arriving at the amount of free silica, its distribution, and its particle size. Chemical procedures also are used (Trostel and Wynne, 1940; Talvitie, 1951).

The abrasive effect of free silica will obviously depend on the type of crushing equipment used and the size of the free silica particles. In general, chert can be expected to gouge and scratch because it occurs in nodules and beds and is likely to be in sizable pieces. Sand is likely to scour, the extent of scouring depending on its abundance and on the firmness with which the sand is held in the limestone or dolomite being crushed. Silt may scour or its effect may be scarcely evident.

Water Absorption

Water absorption of limestone or dolomite is usually expressed as the percent by weight of water absorbed by a given weight of dry stone when the stone is immersed in water for a specified period of time. The test pieces are commonly 2 inches or less in diameter, and a 24-hour immersion is specified for concrete and road aggregates. The test is performed on both fine and coarse aggregates (ASTM, 1961a, p. 605–609).

The water absorption of building stone is determined on sawed pieces of stone that have a regular form and are at least 2 inches in minimum dimension and not more than 3 inches in maximum dimension. The blocks are thoroughly dried and immersed for 48 hours in distilled or filtered water at 20° C plus or minus 5°. Thereafter they are surface dried and weighed. Results are expressed in percent by weight (ASTM, 1961b, p. 755–757).

The water absorption of Illinois limestones and dolomites varies, although in general the dolomites may have a somewhat higher absorption than limestones. Many tests on broken stone show values ranging from 0.2 to 7.1 percent absorption (Krey and Lamar, 1925, p. 47–62; Lamar, 1959, p. 80; Bradbury, 1963, p. 19).

Porosity

The porosity of a rock is the volume of its pores expressed as a percentage of the total volume of the rock mass. It is determined by dividing the

volume of the water absorbed by a sample by the volume of the sample. In some cases porosity is used with the same meaning as water absorption in percent by weight.

Specific Gravity

The specific gravity of a limestone or dolomite specimen is its weight divided by that of an equal volume of water. The apparent specific gravity is determined by weighing a clean dry sample of stone, soaking it in water, and then weighing it suspended in water. The period of immersion is 24 hours for aggregates and 48 hours for building stones (see "Water Absorption," ASTM, 1961a, p. 606).

Apparent specific gravity is calculated by dividing the weight of the dry sample by the weight of the dry sample minus the weight of the sample suspended in water.

To determine bulk specific gravity, a clean dry specimen is weighed, soaked in water for 24 hours, surface dried, reweighed, and then weighed a third time suspended in water (ASTM, 1961a, p. 606). Bulk specific gravity is calculated by dividing the weight of the dry sample by the weight of the surface-dried, water-saturated sample minus the weight of the sample suspended in water.

The specific gravity of 167 samples of Illinois limestones ranged between 2.53 and 2.79 and averaged 2.66; that for 176 Illinois dolomite samples ranged between 2.39 and 2.82 and averaged 2.66 (Krey and Lamar, 1925, p. 47–62; Lamar, 1959, p. 80; Bradbury, 1963, p. 19).

The weight of Illinois limestones, calculated from the specific gravity figures, ranges from 156 to 174 pounds per cubic foot and averages 166; the range for dolomites is from 150 to 175 pounds per cubic foot and averages 166. Further details are shown in table 8.

TABLE 8—PERCENTAGE OF SAMPLES IN VARIOUS WEIGHT GROUPS

Weight (lbs/cu ft)	Percentage of Samples	
	Limestone	Dolomite
150—155	0	4
156—160	6	7
161—165	29	36
166—170	61	39
+170	4	14

Specific Surface, Specific Surface Area, and Surface Area

The terms specific surface, specific surface area, and surface area are used to indicate the total surface area of all the particles composing a given weight or volume of material. They are used in defining and discussing the properties of powders, sand, granules, and larger particles. The specific

surface, or surface area, of powders is commonly expressed in square meters per gram or as square centimeters per gram. The terms would probably be of interest to quarry operators chiefly in connection with the properties of whiting or aggregates.

Soundness Tests

Soundness tests are made to determine the probable resistance of limestones and dolomites to the weather, especially to the effects of freezing water. The sodium sulfate test is used to test aggregates for concrete and other types of roads and crushed stone for railroad ballast and filter beds of sewage disposal plants. Actual freezing and thawing also are used to test road aggregates.

The sodium sulfate soundness test (ASTM, 1961a, p. 600) involves soaking stone samples of stated particle sizes in a saturated solution of sodium sulfate at a temperature of 70° F plus or minus 2° for between 16 and 18 hours. Samples of "ledge rock," such as those that come from outcrops or quarry faces, should weigh about 5000 grams (11 pounds) and the individual pieces composing the samples about 100 grams (3.5 ounces) each. After being soaked, the samples are allowed to drain and are then dried to a constant weight. Each soaking and drying constitutes one cycle. After 5 cycles of the test, pieces that have split into 3 or more parts are considered to have failed. Weight loss is calculated in percent by dividing the weight of the pieces that failed by the weight of the original sample and multiplying by 100.

The permissible weight loss for various types of road aggregates after 5 cycles varies from 10 to 25 percent, depending on the kind of road the stone is to be used for. Filter stone should generally withstand 20 cycles of the sodium sulfate soundness test with little loss of material (ASCE, 1937, p. 9).

Prospecting Limestone and Dolomite Deposits

Prospecting of a limestone or dolomite deposit involves determination of the thickness and character of the stone and its overburden, the evenness of the upper surface of the stone deposit, and, in the case of a thin limestone, the kind of rock beneath it because this may determine whether some of the limestone must be left for the quarry floor. Prospecting is usually done by test drilling, for which a diamond drill, air drill, or some other type of drill is used. The locations of the drill holes should be recorded for future reference, and elevation of the ground surface at each of the borings should be determined if irregularities in the top of the stone or the dip of the stone stratum are considered significant. During the course of the drilling, samples should be carefully kept, including samples of any shale, clay, or other partings encountered. The depth at which the latter materials occurred and their thickness should be noted. If drills that provide chips instead of a

core are used, samples may be saved at intervals of about a foot. In diamond drilling the entire core produced is preserved. Samples of the overburden also are saved in both methods for further examination.

The length of the core produced in diamond drilling should, if possible, equal or approximately equal the depth drilled. In some cases, cores 1 inch in diameter are employed in initial prospecting, but cores approximately 2 inches in diameter are sometimes used to obtain larger samples for testing.

No detailed plan that is applicable to all test drilling can be specified. For thick deposits of known uniformity a fairly wide spacing of drill holes is feasible. If thinner, more variable deposits are to be tested, closer drilling is desirable, possibly with holes no more than 200 feet apart and arranged in a regular pattern like the four spots of a domino. Probably for many thin deposits a flexible plan for drill-hole spacing is needed, with the findings of successive drill holes governing the frequency and location of subsequent holes.

If cores are taken, a geologist should, if possible, examine them and identify the various materials and the varieties of limestone and dolomite present. Insoluble residue tests should be run, if possible, to get a rough estimate of the purity of the stone. On the basis of this information, the core may be divided into various units of different character and purity from which samples may be prepared for chemical and physical tests.

Samples from Cores

Core samples for chemical analysis may consist of the entire core, of slices of equal thickness cut lengthwise from the core by a diamond saw or other means, or of a series of closely spaced chips from the core. The sample should generally weigh at least half a pound and may be much larger than this.

For physical tests a 50-pound sample is required (ASTM, 1961a, p. 581) and the entire drill core, or sizable units thereof, are commonly submitted for such a test.

If test drilling indicates a satisfactory deposit may be present, further confirmation of the nature of the stone is sometimes sought by blasting a hole into the deposit to the depth that it is proposed to quarry the stone. The deposit can thus be inspected and additional samples taken. The sampling procedure followed is the same as that discussed under sampling of outcrops.

Sampling for Chemical Analysis

As quarries and outcrops vary, no one sampling plan will cover them all in detail but, primarily, the samples should accurately represent the variations in the deposit. One or two fist-sized pieces will rarely accomplish this. A quarry usually affords a fair-to-good opportunity to obtain a representative sample, depending on the accessibility of the quarry face and the

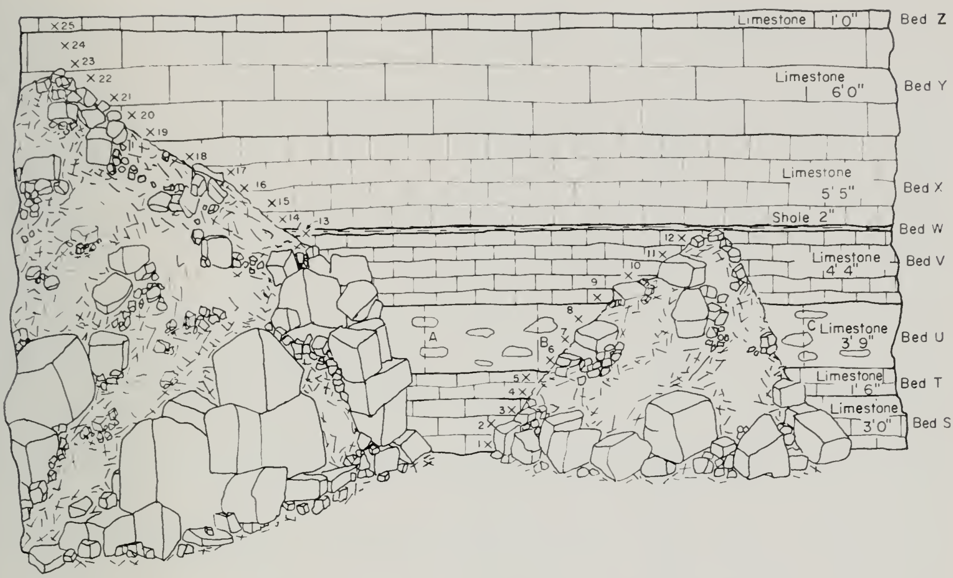

FIG. 47—Quarry face with plan for sampling to determine chemical composition. Samples were taken from the quarry face at the points marked by X's.

extent to which it is covered by slumped overburden or other material. The same is true of natural bluffs of stone, and some continuous outcrops in the beds of streams also may afford satisfactory samples. Many creek and bluff outcrops are discontinuous, however, and sampling them is largely a matter of taking whatever stone is available. The weathered exterior should be removed from each piece of stone in such a sample, and each individual ledge or outcrop should be sampled uniformly so that the sample represents the deposit as fairly as possible. This means that the number of pieces of stone taken from each ledge should be approximately proportional to the thickness of the ledge and also that the pieces from the various ledges should be of about the same size. At best, the results of tests on such samples should be regarded as merely suggestive of the possible nature of the deposit. Test drilling or "opening up" the deposit for sampling by blasting or other means is usually necessary to gain a more specific and detailed knowledge of the character of poorly exposed deposits.

The following detailed sampling plan is presented as an example of a basic procedure that is believed to fit many situations or to be modifiable by a change in the size of the samples and/or the frequency at which they are taken. The illustration (fig. 47) for the plan shows a quarry face, but the plan is also applicable to bluffs or continuous outcrops along creek beds.

The quarry face in figure 47 consists of seven beds of dolomite and limestone, one of them cherty, and a 2-inch bed of shale. The numbers show where samples might be taken at about 1-foot intervals to represent the various beds of the quarry face. The numbers are consecutive from the bot-

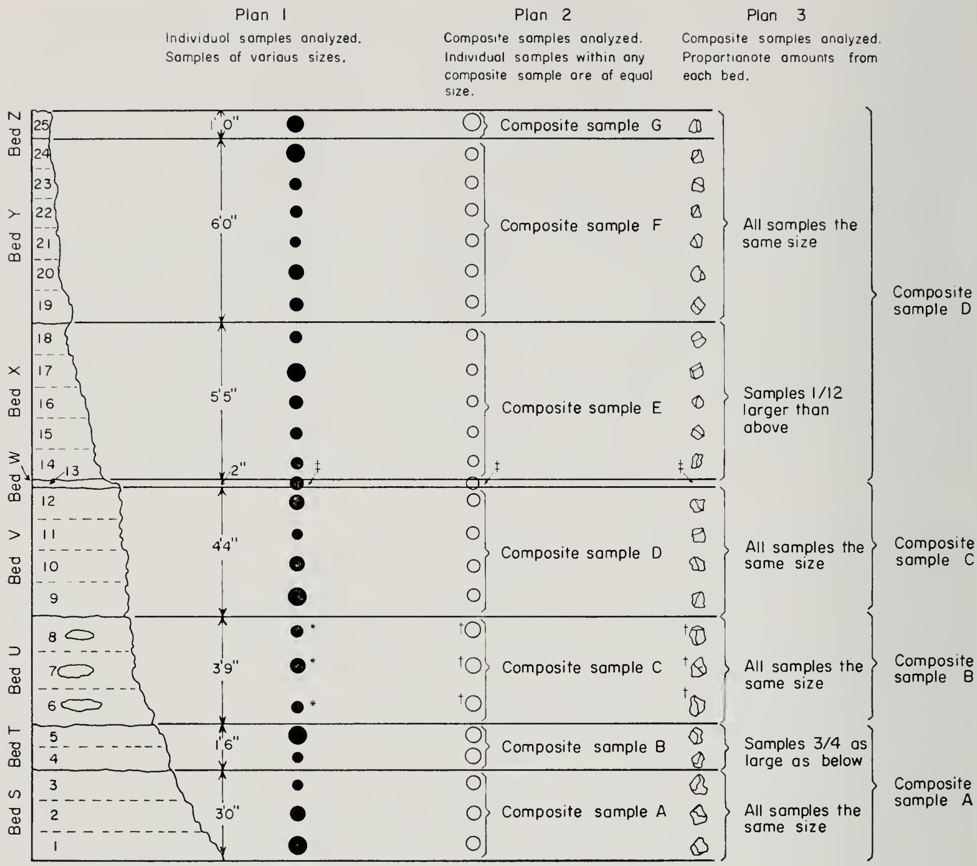

FIG. 48—Three plans of sampling shown graphically. Asterisks indicate chert sampled and analyzed separately. Single daggers indicate chert sampled separately and either analyzed separately or added to composite sample C (plan 2) or sample B (plan 3) in an amount proportionate to its thickness in bed U. Double daggers indicate samples analyzed separately or not analyzed.

tom of the face upward. Each sample should be at least fist-sized, and all dirt and weathered stone should be removed from it. Samples should be labeled and individually wrapped in paper or put in a paper bag.

The chert in bed U poses a special sampling problem. Samples 6, 7, and 8 include no chert. If the bed were sampled at some other place, for instance along the vertical lines A, B, and C, considerable but various amounts of chert would be included. It is necessary, therefore, to get an average figure on the amount of chert present. This can be accomplished by measuring the thickness of the chert encountered along several vertical lines selected at random, such as A, B, and C in figure 47. The thickness of the chert along line A is 11 inches, that along line B is 6 inches, and that along line C is 16 inches, making an average of 11 inches. The amount of chert in bed U is therefore about 24 percent by volume, or about 21 percent by weight, as chert is somewhat lighter than limestone, being 145 pounds per cubic foot, whereas limestone is 165 pounds per cubic foot.

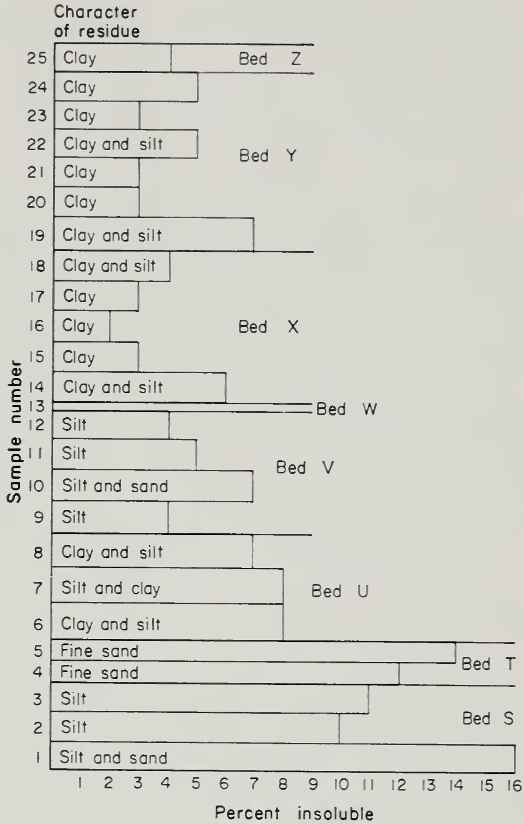

FIG. 49—Insoluble residue data for samples shown in figure 47. The chert in bed U is not included. No residue was run on the shale (bed W). Average residues: entire outcrop, 6.2 percent; beds V to Z inclusive, 4.2 percent; beds S, T, and U, 10.3 percent; beds S and T, 12.6 percent.

There are three principal plans for the further treatment of the samples (fig. 48). In Plan 1, each sample, including the chert, is submitted for a separate chemical analysis. This is a comparatively expensive procedure but gives much detailed information about the variations within the deposit.

Plan 2 involves combining equal amounts of the individual samples from each bed into a single composite sample for chemical analysis. For instance, samples 14, 15, 16, 17, and 18 are combined in equal amounts as a composite sample, as are samples 1, 2, and 3. For the quarry face in figure 47, seven composite limestone samples would be produced and their chemical analyses would show the composition of each of the major beds exposed, but they would not show how much variation there was within individual beds.

Getting equal amounts of the individual samples for a composite is often accomplished by trimming all the individual samples to about the same size. It is more accurately done by trimming each sample to some selected standard weight or by crushing it and weighing out a standard amount.

Plan 3 involves determining the amount and character of insoluble residues present in each of the individual samples by treating them with hydrochloric acid to dissolve the carbonates in them. The results from the quarry face in figure 47 are shown in figure 49. The impurities in beds X, Y, and Z are shown to be chiefly clay or silt and clay. As the insoluble

residues are roughly similar in composition and amount in each bed, a single chemical analysis ordinarily would suffice to indicate the character of the three beds.

The residues from bed V are mainly silt. The bed differs in this respect from the strata above and below it, and therefore a chemical analysis should be made of it. Bed U is cherty and also should have a separate analysis.

Beds S and T are high in impurities. The residues are composed principally of silt or fine sand. As both these materials are likely to be high in silica, these two beds could be analyzed together.

From the insoluble residue data and the analyses of the four composite samples just described, a fairly close estimate of the purity and the impurities of the deposit can be had. Quarrying beds V to Z inclusive would result in a quarry product with an average purity of about 95 percent carbonate. Inclusion of beds S, T, and U would add chert, silt, and sand in appreciable amounts and thus reduce the purity of the quarry output as well as limit its uses for certain purposes.

The preparation of the composite samples for chemical analysis under the foregoing plan would involve (1) combination of the individual samples from beds X, Y, and Z, (2) combination of the individual samples from bed V, (3) combination of the samples from bed U, including the chert in the bed, and (4) combination of the individual samples from beds S and T.

In combinations 2 and 3, each of the samples represents an equal thickness of stone, and, therefore, the individual samples may be combined in equal amounts as previously described.

In combinations 1 and 4, not all the individual samples represent the same thickness of stone. In combination 4, samples 4 and 5 both represent 9 inches of stone, whereas samples 1, 2, and 3 each represents 12 inches of stone. The composite samples representing these beds, therefore, should be a combination of 9 units by weight or volume from each of samples 4 and 5 and 12 units by weight or volume from each of samples 1, 2, and 3.

In combination 1, samples 19 to 25 from beds Y and Z each represent 12 inches of stone, and each of the 5 samples from bed X equals 13 inches of stone. The composite sample from beds X, Y, and Z should, therefore, be prepared by combining amounts of samples 14 to 25 that are proportionate to their thickness.

A shale bed 2 inches thick is present in the quarry face (fig. 47). It makes up 1 percent of beds V to Z, inclusive. The shale sample may be analyzed separately, it may be combined in an amount equal to its thickness with the composite sample for beds X, Y, and Z, it may be included in the composite sample for bed V and the resulting sample analyzed chemically, or the fact that the shale will contribute about 1 percent impurities, chiefly alumina and silica, to the product from beds V to Z combined may be recognized and no analysis made.

A chert sample is taken by collecting pieces from several different nodules. They may be crushed, mixed, and analyzed separately, or the analytical

chemist may be instructed to blend 21 percent by weight of the chert sample with the composite sample for bed U and to analyze the mixture. Another alternative is to bear in mind that the chert is all, or mostly all, silica when considering the results of the chemical analysis of the chert-free stone from bed U.

Sampling Quarries and Outcrops for Physical Tests

The same general plan described for sampling for chemical analysis is followed in obtaining samples for physical tests. However, samples for physical tests should weigh 50 pounds and consist of pieces that are approximately fist sized. Under ordinary circumstances, samples taken from each of the seven beds shown in figure 47 should suffice to indicate the probable physical character of the deposit. However, in the event that an operating quarry is having difficulty meeting physical test specifications, samples should be spaced more closely.

A careful record should be kept of the source, thickness, and character of each physical test sample. Samples should be well labeled and placed in strong bags or boxes for shipment to the laboratory.

Tests or Analyses Needed

When samples are submitted to a laboratory for analyses or tests it is necessary to specify what information is desired. The tests made on a limestone or dolomite sample depend upon the uses for which it is believed or hoped the stone will be suitable. Various uses or use categories are listed in table 9 with the kind of tests made to determine the probable suitability of samples for these purposes. The significance of the various chemical items in relation to the composition of limestones and dolomites was explained under "Wet Gravimetric Analysis." Tests relating to the way in which a stone is prepared, as those for fineness or particle shape, are not listed in table 9 because these can be controlled in the processing of the stone.

Comparison of Outcrop and Quarry Analyses

The accuracy with which chemical data on samples from a limestone deposit are likely to indicate the composition of the commercial stone produced from the deposit is a matter of interest. It depends on many factors that relate to the sampling and to the cleanliness of quarrying. For instance, if the samples were not fresh rock they might prove to be less pure than the quarry product. If the deposit contained thin shale partings along the bedding planes that could not be adequately sampled, the sample data might indicate a purer stone than the quarry product. Similarly, if stripping is not done cleanly or the quarry floor is dirty, the analyses of samples might indicate a purer stone than the ultimate quarry product.

Experience indicates that the calcium carbonate equivalent of commercial agstone from quarries in the Pennsylvanian limestones of Illinois is about 2

TABLE 9—TESTS OR ANALYSES SPECIFIED FOR VARIOUS USES OF STONE

Use of stone	Data required
1. General chemical uses	Chemical analysis for CaO, MgO, SiO_2, Al_2O_3, Fe_2O_3, Na_2O, K_2O, CO_2, and loss on ignition. Sometimes Na_2O, K_2O, and either CO_2 or loss on ignition are not determined.
2. Portland cement	Same as for use 1, including Na_2O and K_2O.
3. Carbide manufacture	Same as for use 1 plus analysis for P_2O_5.
4. Flux	Same as for use 1 plus analysis for SO_3 and P_2O_5.
5. Whiting	Same as for use 1 plus analysis for SO_3, possibly MnO.
6. Lime	Same as for use 1 plus decrepitation test (in some cases).
7. Agricultural limestone	Calcium carbonate equivalent test.
8. Concrete aggregate 9. Aggregate for bituminous roads	Sodium sulfate, freezing and thawing, or other soundness test.*
10. Road rock 11. Railroad ballast	Los Angeles or other wear test.*
12. Filter stone	Sodium sulfate soundness test.
13. Building stone	Specifications vary but may include tests for compressive strength, transverse strength, water absorption, and possibly freezing or thawing or other soundness test.

* Specifications of intended users should be consulted to determine what tests are required.

to 4 percent lower than the calcium carbonate equivalent of the samples taken from outcrops of the same deposits. These limestones are 10 to 15 feet thick and generally thin bedded. Closer agreement of outcrop and quarry analyses was found when the limestones tested were thicker, relatively pure stone, but data are available for only a few such deposits.

A major factor affecting samples is the depth to which the outcrop has weathered. Many limestone or dolomite outcrops in Illinois have been exposed to the weather for thousands of years. Freezing and thawing of water has doubtless caused the exposed surfaces of the stone to chip off and "sand off," and rain and snow water have dissolved some materials from them. In some deposits, ground water moving through the rocks may have introduced or removed materials. Despite these phenomena, or possibly in part because of the erosional effects of some of them, the depth of weathering seen by the naked eye is often only a fraction of an inch, although less obvious effects of weathering may penetrate several feet or more.

Weathering of the exposed portion of an outcrop may decrease its carbonate content. This in effect increases the percentage of any silica and clay present and hence the amounts of silica and alumina shown in the chemical analysis of the stone.

Weathering may also actually increase the amount of silica, clay, and iron oxide in the weathered stone of an outcrop. These substances may be dissolved from the overburden by rain water and carried into the pores of the limestone or dolomite. Ground water passing through the stone also may bring silica, iron oxide, and other substances to the surface or near-surface parts of an outcrop.

Because of the evident number of variables involved, it is impossible to make any specific statement regarding differences between the analysis of weathered rock samples and that of fresh rock in a quarry in the same deposit, but limited data suggest that the amount of silica and iron oxide may be lower in the fresh rock; less alumina also is likely to be present, but this is more uncertain. If the deposits contain shale or sandstone beds, no such generalities apply.

Estimates of Tonnage

It is sometimes desirable to obtain an estimate of the tonnage of limestone or dolomite in a given tract of land. A common figure used in such calculations is the weight per acre foot, that is, the weight of a layer of stone 1 foot thick and an acre in extent. Based on the average weight per cubic foot of 166 pounds for Illinois limestones and dolomites, the following figures are rough approximations of tonnage.

Thickness of limestone or dolomite	Approximate tons per acre
1 foot	3,500
1 yard	10,500
10 feet	35,000

Selection of a Quarry Site

Selection of a quarry site involves many factors, but the existence of a market for the stone and the character of the market are primary considerations. The size of the market available to a proposed quarry site also is important, as it will obviously control the size of any quarry that is developed. As most Illinois quarries ship much or most of their stone by truck, the market of the quarry will depend to a considerable degree on the distribution and character of the roads, especially the all-weather roads, that surround it. If a market served by railroad or barge transportation is planned, the availability of these facilities is an obvious necessity. The nature of the land between the proposed site and rail or water and its effect on the cost of moving the quarry products from the quarry to the shipping point is of considerable importance. Hilly country, poor roads, swampy areas, the need for heavy duty bridges, and other such factors are obviously significant.

Special consideration should be given in the case of quarries near cities to the effect of population movement and suburban development on the scope and character of quarrying operations and the limitations that might be imposed thereon in the immediate and more distant future.

From the geological standpoint it is desirable to determine first where deposits of limestone occur in the selected area and to estimate their general character and thickness from the outcrops available. Geological reports, if

available, should be consulted for information regarding regional or local variations. Any well records in the area should be collected from well drillers in the vicinity and from the State Geological Survey, and the data they contain related to the outcrop information.

A similar survey of the kind of overburden present and its thickness and variations is likewise important, as is information regarding the kind of material underlying the limestone or dolomite deposit. A sandstone below the limestone formation would obviously make a generally serviceable quarry floor, but a plastic clay or shale might necessitate leaving several feet of stone for the quarry floor, either permanently or temporarily.

In areas in which limestone sinks (also known as sink holes) occur, the limestone is likely to contain underground channels through which the water that produced the sinks moved. Some of the channels may still carry water, particularly after periods of heavy rainfall. Obviously these channels, especially if water-bearing, and the caves and crevices produced by ground water may pose problems in quarrying or mining, which should be anticipated in plans for developing such deposits.

The character of the upper surface of a limestone or dolomite deposit should be investigated insofar as possible from the outcrops to make a

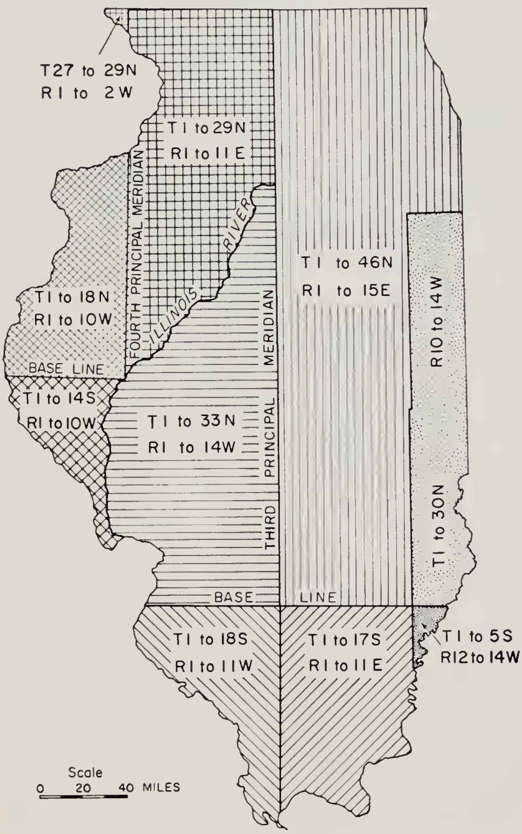

FIG. 50—Map showing the two principal meridians and two base lines in Illinois used in locating land. Locations in the dotted tracts along the east edge of the state are related to the Second Principal Meridian, which is in Indiana, and to the base line in southern Illinois. The four lined areas are related to the base line in southern Illinois and the Third Principal Meridian. The four cross-hatched areas are related to the base line in western Illinois and the Fourth Principal Meridian. The numbers in each of the areas indicate the township and range numbers within the area. T is the abbreviation for township and R is the abbreviation for range. N and S indicate the direction of a township or range in relation to the appropriate base line. E and W indicate their direction in relation to the appropriate meridian.

preliminary estimate of whether the surface is even, moderately rough, or quite irregular. A limestone or dolomite deposit having an even top is easy to strip clean, but stripping an irregular top clean is more difficult and may involve the removal of spires and ridges of stone.

The tops of limestone or dolomite deposits that occur in areas of sink holes or in sharply hilly areas are likely to be irregular. Geologically speaking, limestone or dolomite areas that have been exposed to weathering and erosion for a long period are likely to have irregular tops unless some erosive force, such as glaciation, has planed off the irregularities. The tops of deposits occurring in the valley flats of streams are likely to be unevenly channeled. Stone deposits overlain by glacial deposits may have a comparatively even surface or one of moderate roughness.

Data from outcrops regarding the probable character of the surface of a limestone or dolomite deposit should be augmented by results of test drilling. The outcrop data can be helpful in directing and interpreting such drilling.

The possibility of working a limestone or dolomite deposit by underground mining instead of open pit quarrying may be considered, if factors such as the thickness and character of overburden, character of rock top, and the thickness of the stone are favorable. Good roof conditions are essential for underground mining. The worked-out parts of underground limestone mines of suitable size and geographic location have considerable economic value for the storage of a wide variety of materials (Anderson, 1965, p. 106).

Location of Areas and Points

Meridians and Base Lines

To enable exact locations of places and tracts of land in Illinois to be found, their locations are related to certain lines of reference. These include three principal meridians and two base lines. The meridians have a north-south direction, the base lines an east-west direction. Figure 50 shows the two base lines and the Third and Fourth Principal Meridians. The other principal meridian involved, the second, is located in Indiana; locations of tracts or points in a north-south area along the east edge of the state are referred to it (fig. 50).

Townships

The state is divided into townships, which are of two kinds. The first is sometimes referred to as a civil township. The second does not have a name in widespread use and is herein referred to as a "land survey" township for convenience. Land survey townships are normally about 6 miles square. The location of these townships is expressed with reference to the meridians (east or west) and base lines (north or south) previously discussed (fig. 51).

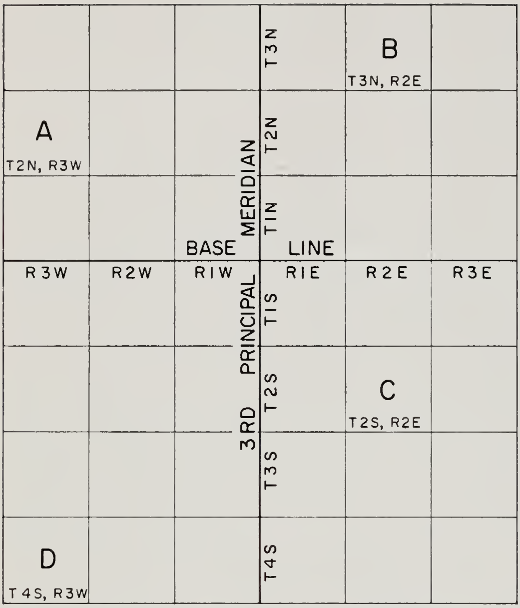

FIG. 51—Drawing showing how a number of land survey townships are designated. The township bearing the letter A would be described as T. 2 N., R. 3 W.; township B is T. 3 N., R. 2 E.; township C is T. 2 S., R. 2 E.; and township D is T. 4 S., R. 3 W.

It is evident in figure 50 that there is a T. 20 N., R. 10 E. related to the Third Principal Meridian and also a T. 20 N., R. 10 E. related to the Fourth Principal Meridian, as well as a considerable number of similar duplications. Therefore, when the location of a piece of land is specified it may be necessary to indicate which principal meridian is involved. However, as Illinois is divided into counties and as the land in most counties is related to only one of the principal meridians, sometimes only the county name is given with the township and range.

Sections

Each land survey township normally consists of 36 sections, each about one square mile in area, or about 640 acres. The sections are numbered as shown in figure 52. A section number, therefore, indicates the location of a specific tract within a land survey township.

6	5	4	3	2	1
7	8	9	10	11	12
18	17	16	15	14	13
19	20	21	22	23	24
30	29	28	27	26	25
31	32	33	34	35	36

FIG. 52—Numbering of sections within a township.

The location of a tract or a point within the ordinary section is commonly based on the division of the section into quarters, as shown in figure 53A. Each of the quarters is approximately half a mile square, contains 160 acres, and is known as a quarter section.

In the further subdivision of a section each quarter section is itself divided into four parts, as shown in figure 53B. The 16 tracts thus formed are known as quarter, quarter sections. Each contains approximately 40 acres.

Sometimes it is necessary to subdivide a section further into still smaller units, especially for the location of specific features, such as a quarry or a

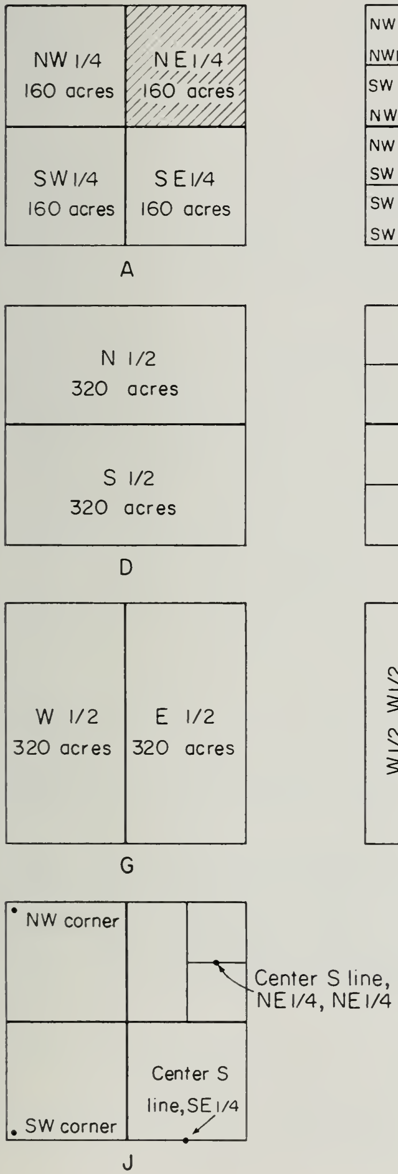

FIG. 53—Ways in which a section may be divided to permit the location of tracts of land or a specific place, such as the site of a quarry. Key is on facing page.

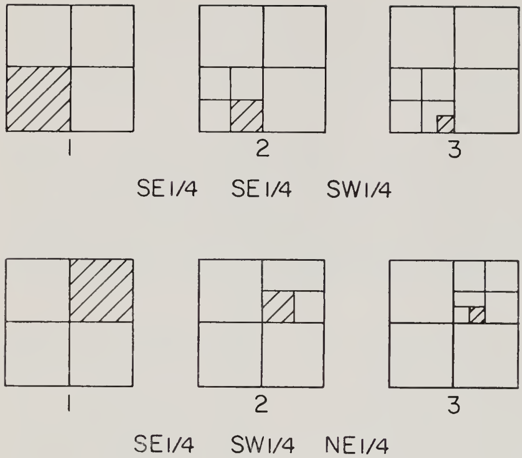

FIG. 54—Two examples of how a location given in quarter, quarter, quarter sections is found on a map by plotting the quarter, quarter, quarter sections in reverse order.

limestone outcrop. In this case each quarter, quarter section is divided into four parts known as quarter, quarter, quarter sections. Each contains approximately 10 acres. Examples of the use of these subdivisions are shown in figure 53C. Other methods of locating various tracts and sites within a section are shown in figure 53D–J.

Written descriptions of the locations of tracts of land by quarter sections begin with the smaller subunit of the section and proceed to the larger. Thus NE¼ SW¼ sec. 20 means the northeast quarter of the southwest quarter of section 20; the southwest quarter of the section is the larger of the two units. The location SE¼ SW ¼ NE¼ sec. 3 means the southeast quarter of the southwest quarter of the northeast quarter of section 3. In this case the northeast quarter of the section is the largest unit, the southwest quarter the next largest, and the southeast quarter the smallest unit (fig. 54).

In locating specific places in a section it is assumed that they are at or near the center of the tract described. For example, location of a quarry is

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KEY FOR FIGURE 53

A. Division of section into quarter sections. The shaded area is described as the northeast quarter (NE¼) of the section.

B. Division of a section into quarter, quarter sections. The shaded area is described as the southwest quarter of the southeast quarter of the section; generally written SW¼ SE¼.

C. Division of a section into quarter, quarter, quarter sections, usually written ¼, ¼, ¼. Shaded area 1 is described as the northeast quarter of the northeast quarter of the northeast quarter of the section, commonly written NE¼ NE¼ NE¼. The shaded area 2 is the SE¼ SE¼ NW¼ of the section; shaded area 3 is the NW¼ SE¼ SE¼ of the section; shaded area 4 is the SW¼ NE¼ SW¼ of the section; point A is in the NW¼ NE¼ NW¼ of the section; point B is in the SW¼ SE¼ NE¼ of the section; and point C is in the SW¼ SW¼ SW¼ of the section.

D. Division of a section into north and south halves.

E. Further division of half sections.

F. Division of quarter sections into north and south halves.

G. Division of section into east and west halves.

H. Further division of half sections.

I. Division of quarter sections into east and west halves.

J. Examples of special kinds of locations.

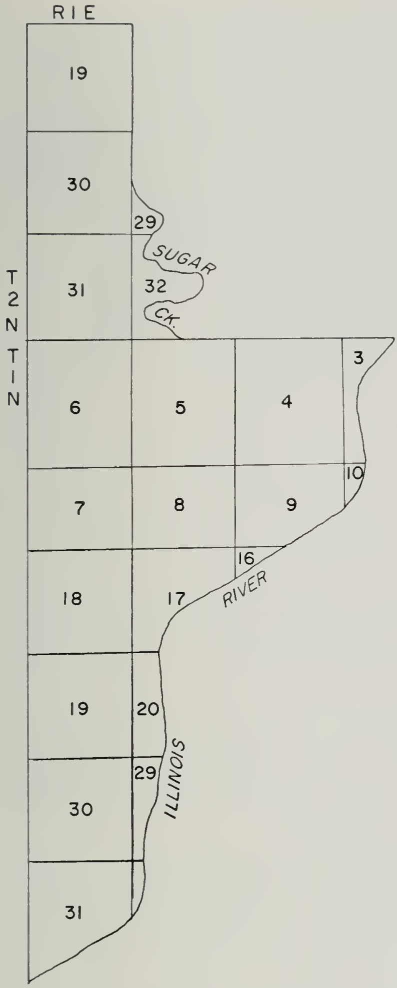


FIG. 55—Frederick Township in Schuyler County. The eastern margin of the township is largely controlled by two streams. There are two sections numbered 19, 29, 30, and 31 in the township, but they are distinguished by being in T. 1 N. and T. 2 N. Details of map not exact.

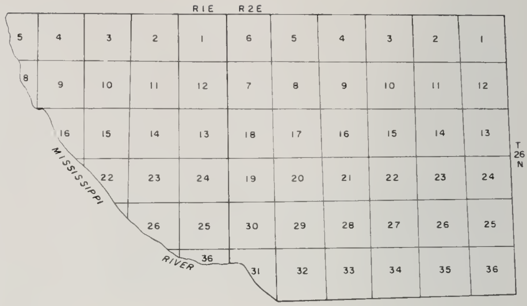
given as being in the NE¼ NW¼ sec. 31. This is taken to mean that it is located at or near the center of the NE¼ NW¼ of section 31. Similarly, a location of a quarry in the S½ N½ sec. 33 would be at or near the center of the S½ N½ of section 33.

When a location of a specific site is given, the procedure for finding the site on a map involves determining first the correct township, range, and section. The description within the section, for example, SE¼ SW¼ NE¼, is then followed in reverse order, that is, from the largest to the smallest unit. The NE¼ is first found, then the SW¼ of the NE¼, and finally the SE¼ of the SW¼ is located. The procedure is shown in figure 54.

Civil Townships

Civil townships in Illinois vary in size and shape although many of them coincide with land survey townships. They have names, such as Quarry Township, Rockbridge Township, or Sullivan Township, which relate to

FIG. 56—Hanover Township, Jo Daviess County. The western margin of the township is controlled by the Mississippi River. The north, south, and east boundaries of the township coincide with the boundaries of land survey townships. The township consists of one almost complete land survey township and a major part of another. Sections having the same number are distinguished by being in either R. 1 E. or R. 2 E. Details of map not exact.



some feature or person of importance when the township was defined, to some town within the township, or to some other matter. Civil townships are, as their names imply, political units and have elected officers, such as road commissioners. Their limits are, in some cases, streams or other natural features. A civil township may include one land survey township, a part of one land survey township, or parts of two or more land survey townships. Figures 55 and 56 show two civil townships that have interesting characteristics.

Topographic Maps

Topographic maps show the contour, or "lay," of the land by a series of lines known as contour lines. They also show the elevation of the land surface, rivers and streams, and man-made features such as roads, railroads, and houses. They are useful for a variety of purposes.

The basic principal of topographic maps is shown in figures 57 and 58, which are photographs of a model representing an island. The model is made up of five layers of wood, each of which is a half-inch thick except the thinner upper one. Metal rods hold the model together. Below each layer of wood a layer of paper protrudes slightly, and the resulting white lines represent contour lines. Each white line is the same vertical distance from the line above and below it. This is a characteristic of contour lines. The vertical distance between successive lines in the model is a half inch, that is, the thickness of the wood layers. This is the contour interval. On most topographic maps the contour interval is 5, 10, or 20 feet and is so indicated on the map.

Figure 59 reproduces the white lines in figure 57 and is a topographic map of the island of that figure.

Figure 60 is a copy of part of an actual topographic map. The figure caption points out the many features shown by the map. The manner in which differences in elevation are determined from topographic maps is illustrated by the following example. Suppose it is necessary to determine the difference in elevation between the top of hill G in the bottomlands of the river and hill F on the uplands. As the interval between contour lines is 10 feet, the top of hill G is seen to be higher than 610 feet but lower than

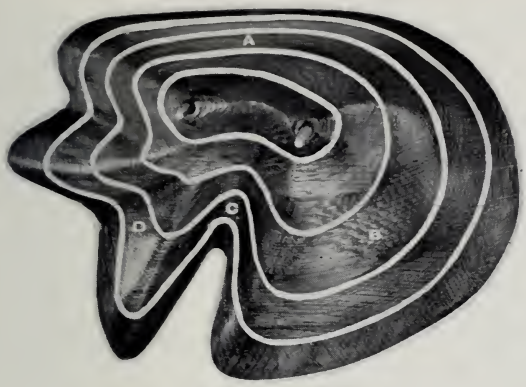


FIG. 57—Model of an island, viewed from above, showing contour lines. A is a steep slope, B is a more gentle slope, C is a steep-sided narrow valley, and D is a more gentle valley. The white lines are the same vertical distance apart.

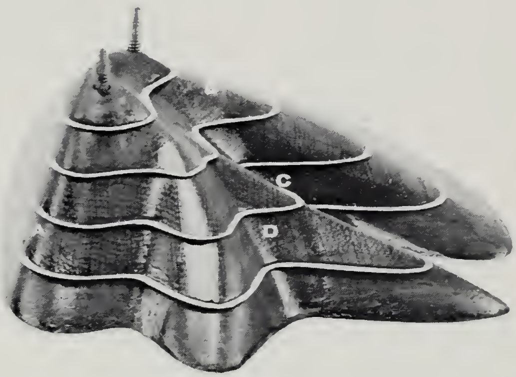


FIG. 58—Side view of a model of an island, showing contour lines. As in figure 57, A is a steep slope, B is a gentle slope, C is a steep-sided valley, and D is a more gentle valley.

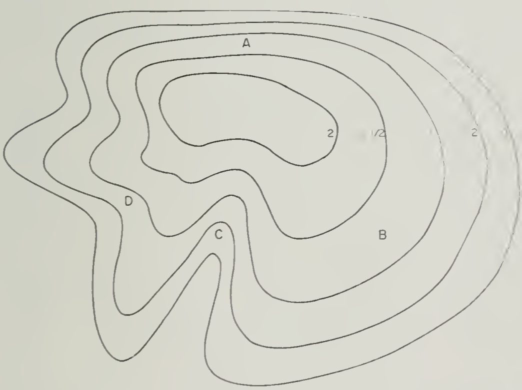


FIG. 59—Topographic map of the island in figures 57 and 58. The difference in elevation between any two adjacent lines is a half inch. On steep slopes (A) the contour lines are close together; on gentler slopes (B) they are farther apart. The contour lines representing a valley make a V that points up the valley (C and D). The V is narrowest where the valley is sharp and narrow (C) and broader where the valley is wider and less steep (D). The difference in elevation between the contour lines 0 and 1 is 1 inch, between lines ½ and 2 is 1½ inches, and so on.

620 feet because there is no 620 contour line on the hill. The top of hill F is higher than 670 feet but lower than 680 feet. The difference in elevation is therefore between 50 and 70 feet.

The topographic maps issued by the U. S. Geological Survey, the chief source of such maps, use brown for the contour lines, blue for streams and lakes, black for houses, roads, railroads, and the like, and red for major

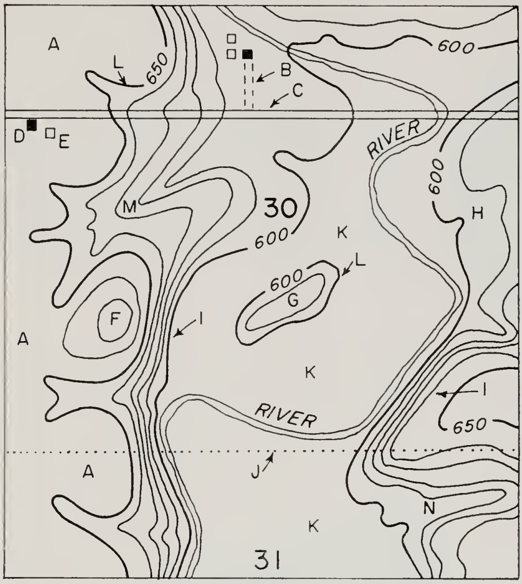


FIG. 60—A copy of a part of an actual topographic map. In the original the contour lines are brown, the river blue, the section numbers and lines red, and the road, houses, and barns black. The sketch covers an area 1 mile wide and the contour interval is 10 feet. The letters on the map call attention to the following:

A. Flat upland area
B. Lane
C. Road
D. Farm house
E. Barn
F. Hill on uplands
G. Low hill in the flat bottomlands of the river
H. Gentle slope
I. Steep slopes forming river bluffs
J. Boundary line between sections 30 and 31
K. Flat bottomlands along river
L. Numbered contour line. The number is the elevation above sea level.
M. Valley extending in a southwesterly direction
N. Valley extending in an easterly direction

highways and, on some maps, for section lines and section numbers. The colors make the maps more easily understood and used than figure 60.

Topographic maps made by the U. S. Geological Survey in cooperation with the Illinois State Geological Survey are available for the entire state of Illinois; similar maps are available for many other parts of the country. The maps may be obtained from the U. S. Geological Survey, Washington, D. C. 20242, for a nominal fee. The Illinois Geological Survey, Urbana, Illinois 61801, also sells the maps of Illinois as a convenience to the citizens of the state.

The topographic maps of Illinois generally are issued on one of two scales—either approximately 1 inch equals 1 mile, or 2⅝ inches equal 1 mile. The former scale is also referred to as 1:62,500, meaning that an inch on the map is equal to 62,500 inches on the ground. The scale of 2⅝ inches equal 1 mile is said to be 1:24,000, meaning 1 inch on the map is equivalent to 24,000 inches on the ground. The area covered by each map is known as a quadrangle and the maps are known as quadrangle topographic maps. Each quadrangle has a name—for instance, the Harrisburg Quadrangle. The 1:62,500-scale quadrangle maps cover an area that is about 13 miles in an east-west direction and 17½ miles from north to south and are commonly referred to as 15-minute quadrangles. The area covered on the 1:24,000-scale is roughly 6.4 miles from east to west and 8.7 miles from north to south. Quadrangles having this scale are called 7½-minute quadrangles. An "Index to Topographic Maps of Illinois" is available without charge from both the Illinois State Geological Survey and the U. S. Geological Survey.

The U. S. Army Map Service prepares another group of topographic maps on a scale of 1:250,000, or about one-quarter of an inch equals 1 mile,

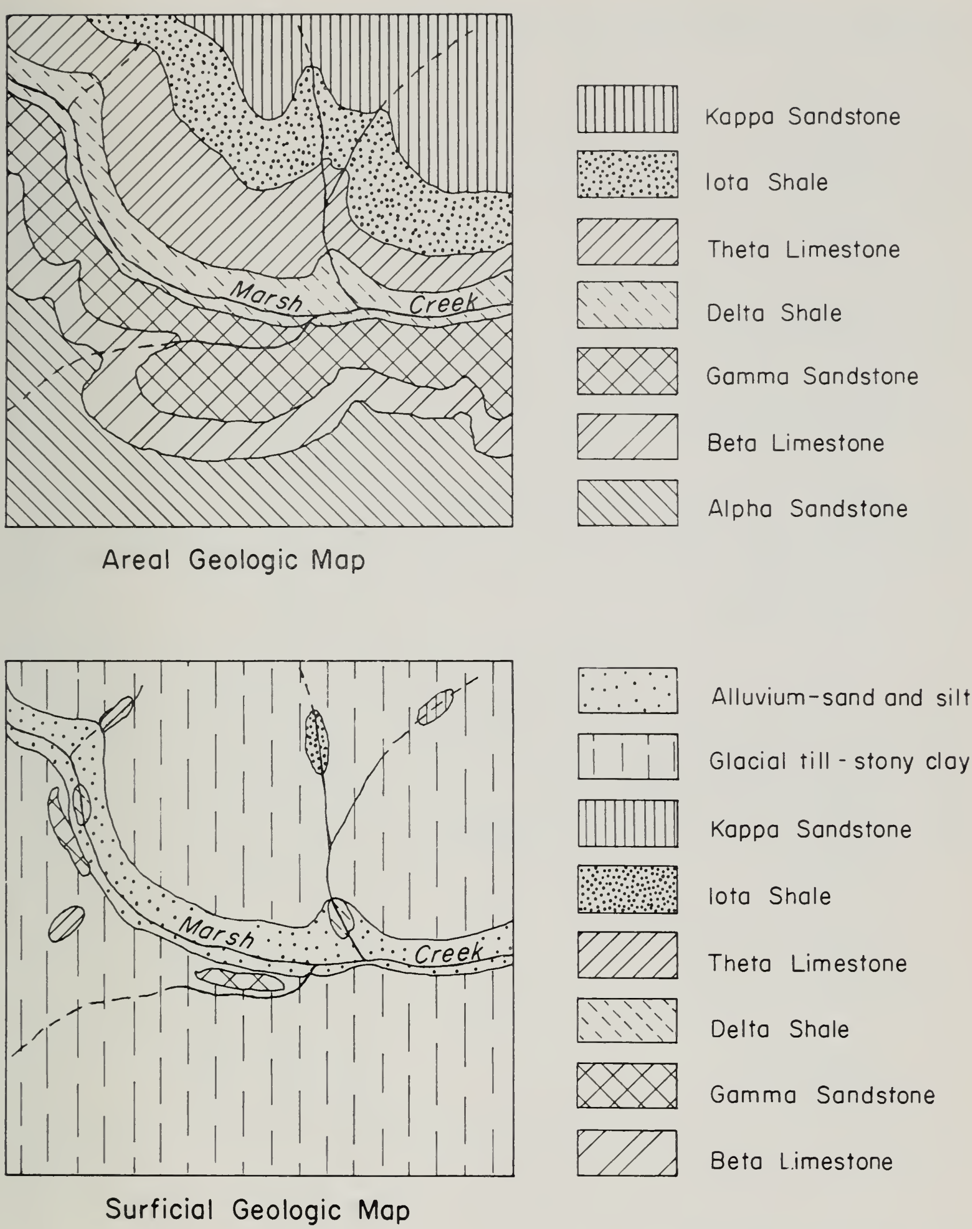


FIG. 61—Areal geologic map and surficial geologic map of an assumed area. (Map by James W. Baxter, 1967.)

that have a contour interval of 50 feet. Each map covers an area about 100 miles wide in an east-west direction and 70 miles in a north-south direction. These maps also are available from the Illinois and U. S. Geological Surveys.

TABLE 10—METRIC AND AMERICAN EQUIVALENT UNITS OF MEASURE

AMERICAN TO METRIC		
American		Metric*
	Distances	
1 inch		2.54 centimeters
1 foot		30.48 centimeters
1 yard		91.44 centimeters
1 rod		5.03 meters
1 mile		1.61 kilometers
	Weights	
1 ounce		28.35 grams
1 pound		453.59 grams
1 ton (short)		907.18 kilograms
	Areas	
1 square inch		6.45 square centimeters
1 square foot		929.00 square centimeters
1 square yard		0.84 square meters
1 square mile		2.59 square kilometers
1 acre		4047 square meters
	Volumes	
1 cubic inch		16.39 cubic centimeters
1 cubic foot		0.03 cubic meters
1 cubic yard		0.77 cubic meters
1 quart (liquid)		0.95 liters
1 gallon		3.79 liters

METRIC TO AMERICAN		
Metric*		American
	Distances	
1 centimeter		0.39 inches
1 meter		1.09 yards
1 kilometer		0.62 miles
	Weights	
1 gram		0.04 ounces
1 kilogram		2.20 pounds
	Areas	
1 square centimeter		0.16 square inches
1 square meter		1.20 square yards
1 square kilometer		0.39 square miles
	Volume	
1 cubic centimeter		0.06 cubic inches
1 cubic meter		1.31 cubic yards
1 milliliter		0.06 cubic inches
1 liter		61.02 cubic inches

* 1 meter = 100 centimeters; 1 kilometer = 1000 meters; 1 kilogram = 1000 grams; 1 liter = 1000 milliliters.

Geologic Maps

There are a number of kinds of geologic maps, but the areal geologic map and the surficial geologic map probably are the most common. The areal geologic map (fig. 61) shows by a series of colors and/or patterns the distribution of the bedrock formations as they would appear if their covering of soil, clay, silt, sand, or gravel was removed. Maps of this sort vary in accuracy depending on the number of outcrops that occur, the number of different formations involved, the distribution of the formations, the amount

of test boring or well data available, and other factors. An areal map is the geologist's best opinion of the distribution of the bedrock formations, based on the information available.

The surficial geologic map (fig. 61) indicates by colors and/or patterns the distribution and character of the earth materials that occur at the surface of the ground. They show the distribution of clay, sand, gravel, and similar materials as well as the outcrops of the bedrock formations and the kind of rock or rocks composing them.

In general, anyone interested in sites for the quarrying of limestone probably would find the surficial map (fig. 61) the more useful because it shows the location of outcrops and gives an idea of the kind of overburden on them. An areal map would be more useful in tracing the distribution of a limestone formation where it is unexposed and in predicting the nature of the rock deposits under any specific tract of land.

Geologic maps on topographic quadrangle map bases are available for certain parts of Illinois, especially the extreme southern and northeastern parts of the state, and may be obtained from the Illinois State Geological Survey.

Metric Weights and Measures

In many parts of the world the metric system rather than the one employed in the United States is used for weights and measures. There is a growing acceptance of the metric system in the United States and the data in table 10 show the metric and American equivalents for weights and measures that apply to the stone industry.

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